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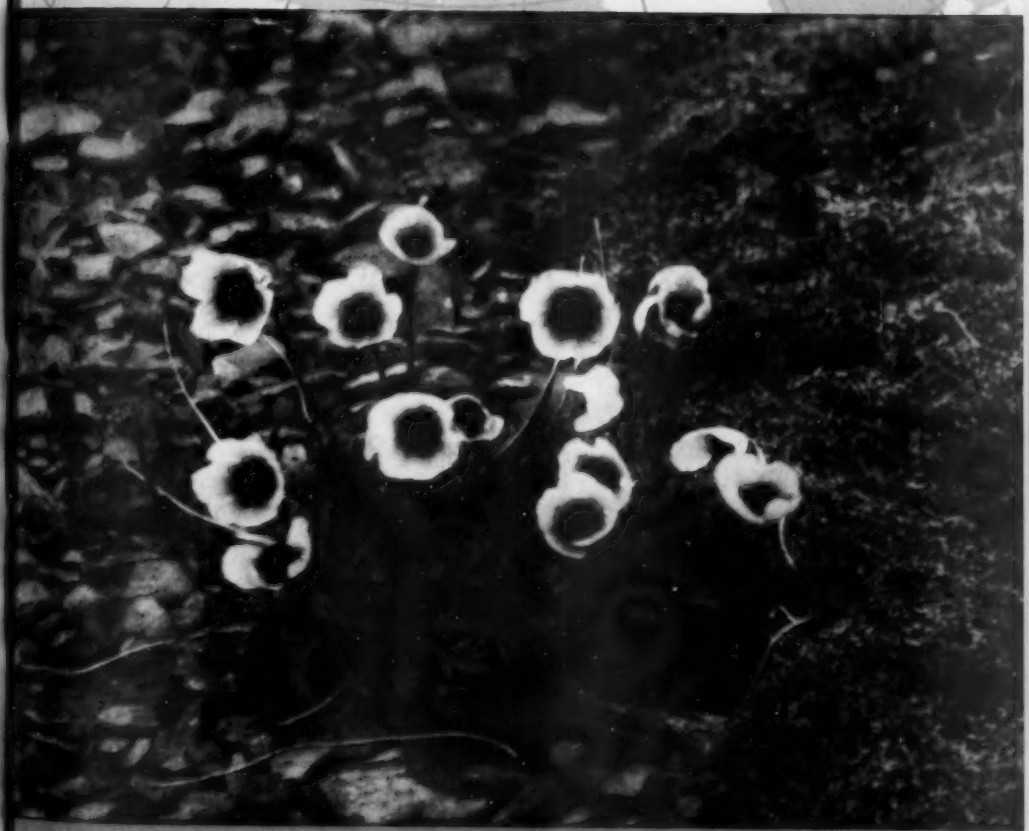

JOURNAL OF THE ARCTIC INSTITUTE OF NORTH AMERICA

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Photo: A. I. Zubkov

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Fig. 1. *Arctophila fulva* (Trin.) Anders. in a shallow pond.

Photo: A. I. Zubkov

Fig. 2. A fragment of *Dryas octopetala* tundra.

SOME REGULARITIES IN THE DISTRIBUTION OF THE VEGETATION IN THE ARCTIC TUNDRA*

V. D. Aleksandrova†

THE necessity for dividing the tundra area into subzones had been recognized in the nineteenth century, and during that century and at the beginning of the twentieth it was frequently mentioned by Baer, Ruprecht, Schrenk, Tanfiliev, and Pohle. Trautfetter (1851) showed on the map of European Russia a "tundra region" and subdivided it into two districts: that of "alpine willow", which approximately corresponds to the present "arctic tundra" subzone, and that of "dwarf birch", which approximately corresponds to the present "typical (or moss and lichen) tundra" and "dwarf shrub tundra" subzones (*see* Phytogeographical Map of the U.S.S.R., Scale 1:4,000,000, Acad. of Science of the USSR Press, Leningrad, 1956). It was not until 1916 that Gorodkov in his classic "An attempt to divide the west Siberian lowland into phytogeographical districts" (Gorodkov 1916) provided the first division of the large northern area between the Urals and the Yenisey River into well-defined phytogeographical districts. Among them he recognized and described the "arctic tundra" subzone, which there includes the northern parts of the Yamal and Gydan peninsulas and borders in the south on the "typical tundra" subzone. The term "arctic tundra subzone" was applied to the northernmost floristic subzones in the USSR also by Berg (1930), but he did not show their boundaries on account of lack of data.

In the early 1930's many workers tackled the problem (Andreev 1932, Gorodkov 1933, Reverdatto 1931, Sambuk and Dedov 1934, Sochava 1933a, 1933b, 1934, and Tsinzerling 1932). The majority of these writers used the terms "arctic" or "polygon" tundra. The vegetation zones for the whole "Far North" of the U.S.S.R. were first delimited by Gorodkov (1935). He recognized at the same time that the northernmost part of the continent and the islands in the Arctic Ocean constitute a disinct geographic and vegetation zone, the so-called snow zone, which he divided into the two subzones: "desert-glacial" and "arctic desert". Consequently, a part of the region included in the arctic tundra subzone was now considered to belong into the arctic desert subzone. This was a further step toward a detailed classification of the vegetation of the "Far North".

* Authorized revision by the editor of the author's translation of her article "Nekotorye zakonomernosti razmeshchenya rastitel'nogo porkrova v arkticheskoy tundre" in Problemi severa, Ak. Nauk SSSR. 1:173-87, 1959.

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According to Gorodkov the arctic tundra subzone is characterized by the following features: (1) absence of shrub communities due to the severity of the climate, the short growing period, and the extreme variation in the depth of the snow cover; (2) occurrence of dry Dryas-moss communities on the sufficiently drained clayey soils, which are however replaced over large areas by barren polygon tundra, especially in situations exposed to intense wind action and with consequently very thin snow cover; (3) the occupation of a large part of the area by arctic bogs, chiefly sedge-moss marshes; (4) the small differences between the vegetation of the uplands and that of river valleys, due to the short periods of inundation in the latter and the shallowness of the active layer.

This characterization by Gorodkov is excellent. It clearly recognizes the fundamental peculiarities of the vegetation, which apply to the subzone as a whole despite the wide regional variations and it points out the differences between this subzone and the typical tundra subzone to the south and the arctic desert subzone to the north.

Important contributions to the division of the tundra into subzones and to the definition of the boundaries of the subzones were made by others, for instance, by the investigations by Andreev in the Yamal Peninsula and in the northern parts of the European tundra (Andreev 1935, 1938, 1947, and (1950), by Zubkov in Novaya Zemlya (Aleksandrova and Zubkov 1937), Govorukhin in the northern parts of the European tundra and the arctic Urals (Govorukhin 1954, 1957), Leskov in the northern part of the European continent and other areas (Leskov 1947), Igoshina in the arctic Urals (Igoshina 1933; Andreev, Igoshina, and Leskov 1935), Tikhomirov (1948a, b) in the Taimyr Peninsula, Sheludyakova (1938) in the north of the Yakut Republic, and others.

The arctic tundra subzone has characteristic zonal features, which were described by Gorodkov. Nevertheless, this subzone is by no means homogeneous over its vast extent. Variations are caused by differences in the history of its geomorphology, climatic conditions, relief, and soil substratum. One finds such contrasts as those between Wrangel Island, which was never glaciated and has a rich and ancient flora, the Taimyr Peninsula with a decidedly continental climate, and Novaya Zemlya, which was several times overrun by ice and has a pronounced maritime climate and a very youthful flora, etc. Gorodkov was able to distinguish five provinces within the arctic tundra subzone of the U.S.S.R. in 1935. Leskov, in co-operation with Gorodkov, drew up a division of the tundra zone of the U.S.S.R. into phytogeographical districts and was able to distinguish eleven different provinces in the arctic tundra "belt" (Leskov 1947).

The vegetation of the arctic tundra subzone has by no means been adequately investigated. Besides comparatively well-studied areas such as Wrangel Island (Gorodkov 1943, 1946, 1958a, b) and the northern part of the Yamal Peninsula (Gorodkov 1916; Andreev 1935, 1938) we have others, e.g., the region between the Yana and Indigyrka rivers, where no botanical investigations have been made. In contrast the South Island of Novaya

Zemlya, considered below, is one of the most intensively studied areas (Baer 1838; Zubkov 1932, 1935; Regel 1932, 1935; Aleksandrova 1937a, b, 1945, 1956; etc.).

The peculiar character of the flora of Novaya Zemlya can be explained by the interaction of three factors: (1) the strictly maritime climate, (2) the youthfulness of the flora and geomorphology, (3) the ruggedness of the landforms and the prevalence of stony ground.

In winter the weather of Novaya Zemlya is under the influence of the Icelandic cyclone from which a trough of low pressure extends eastward across the islands. The arctic front, which separates the cold arctic air masses from the warmer maritime air, tends to lie along this trough. These features explain why Novaya Zemlya has comparatively high winter temperatures (the average temperature for March, the coldest month, at Malye Karmakuly is only –15.5°C.) and frequent long periods of high winds. The circulation, which in itself is strong and vigorous, becomes modified and intensified by the mountain chains across its path and thus gives rise to the well-known "bora" of Novaya Zemlya (a katabatic wind, similar to the cold wind of the same name of the northern Adriatic). In spite of the relatively high temperatures, the winter climate of the islands is extremely severe. In order of climatic rigour Malye Karmakuly stands first in the Soviet Arctic: the severity of the climate, calculated according to Bodman's formula (Vize 1940) is 6.1 for the winter and 4.0 for the whole year.

In summer the position of the cyclone shifts to the continent. This shift causes the air over the Arctic Ocean to move toward the mainland, and Novaya Zemlya comes under the influence of cold arctic air masses, which explains why the summers are cold (the average temperature for the warmest month at Malye Karmakuly is 7.0°C.), windy, with sudden changes of the weather, frequent drizzle and fog, and high relative humidity. The absolute minima for every month lie below the freezing point and thus frost is liable to occur in any month. In winter the absolute maxima lie above the freezing point and there is the possibility of a thaw in any month. The cold summers, the strong winds, the great variations in the depth of the often inadequate snow cover, all these peculiarities of the climate exert a profound influence on the vegetation of the area.

Some features of the vegetation of Novaya Zemlya are in large measure due to the youthfulness of the flora. There were no refugia for the preglacial plant species on the islands since during the maximum glaciation their whole area was covered with ice and there was also a maritime transgression of considerable magnitude. The youthfulness of the flora has been demonstrated convincingly by many investigators (Tolmachev 1922, 1930, 1931, 1936; Lynge 1923, 1928; Steffen 1928; and others). Tolmachev asserted that the main body of the flora is of interglacial origin (Tolmachev 1936).

The opinion held by Krechetovich (1946) and Oksner (1946) that Tertiary relicts exist in Novaya Zemlya is undoubtedly wrong since it is incompatible with glacial history and contradicted by the present flora. Recently the age of high coastal marine terraces has been determined more accurately

(Zagorskaya 1959) and it has been proved that they were formed during the inter-glacial marine transgression. This has led to the realization that the flora of Novaya Zemlya is much younger than Tolmachev thought and that plants did not recolonize the area until late-glacial or post-glacial times.

The youthfulness of the flora explains the almost complete lack of endemics; the islands have only three endemic species that all belong in *Taraxacum*, a genus well known for its polymorphism and capability of producing new forms rapidly. The youthfulness of the flora may also account for peculiarities in the distribution of some plants. The differences between the floras of the east and west coasts are well known (Kjellman 1882, Steffen 1928, Tolmachev 1936). On the east coast several East-Siberian species are found, as for instance *Lagotis stelleri, Minuartia macrocarpa, Erysimum pallasii,* which are absent from the west coast. At the mouth of the Savina River, which runs into the Kara Sea, *Sieversia glacialis* was found (Aleksandrova 1935), which does not occur on the west coast. Such an excellent observer as Tolmachev did not find this species around the east end of Matochkin Shar and its absence from there is unquestionable. It is thus confined to a small part of the Kara Sea shore of the South Island. We can assume that *Sieversia glacialis* reached Novaya Zemlya only recently. It is possible that its seeds were transported by wind during the winter across the ice-covered Karskye Vorota (Kara Strait) and Kara Sea (on the distribution of arctic plants by wind see Tikhomirov 1951).

The youthfulness of the flora also explains the absence of *Lloydia serotina* and the nearly complete lack of ericaceous shrubs, which are so common in Greenland, for instance. This lack had already been pointed out by Baer (1838). That the flora of the islands is very young is obvious, since it came into existence only recently (on a geological time scale), and its development is still going on.

Lynge (1928) wrote: "On the whole it is impossible to avoid the impression of a young flora in Novaya Zemlya. It is very probable that the flora would have been richer if it had been older."

It is an important fact that during the post-glacial thermal maximum, when a considerable northward shift of the tree line took place (Tikhomirov 1941, Zubkov 1948), no trees reached Novaya Zemlya. This is proved by the complete lack, at least north of the 71st parallel, of any remains of quaternary tree wood (except drift wood). Apparently shrub tundra with stands of willows and hummocky peat bogs prevailed in Novaya Zemlya during the post-glacial thermal maximum. The remains of quaternary peat bogs have been observed by several investigators (Zubkov 1932, Kudryashev 1925). The author saw them not only on the western, but also on the eastern side of the South Island. Such species as *Vaccinium uliginosum, V. vitis-idaea, Pyrola grandiflora, Betula nana,* and *Comarum palustre,* which are rare, always sterile and occur only in isolated localities, and perhaps also *Rubus chamaemorus,* seem to be relicts from the post-glacial thermal maximum in Novaya Zemlya.

The most conspicuous features of the Novaya Zemlya landscape are the prevalence of strong relief and the wide distribution of stony ground. The whole aspect of the vegetation is strongly influenced by them and this explains why many authors (the first was Baer) raised the question whether tundra exists at all in Novaya Zemlya. The cause for differences in opinion is mainly the lack of sufficiently drained (within the limits of climatic possibilities) upland areas of clayey soils. Many explorers who happened to land in a region where, as at the Kostin Shar, diabase and limestone predominate, did not see a sufficiently developed zonal vegetation (the "climatic climax"), which is, however, well represented in the regions of the strand flats. In many instances the investigators did find the vegetation types of stony ground (various types of lithosere), alpine tundra or polar desert as precursors of the next vegetation zone ("preclimax") or vegetation affected by high altitude.

Another reason for the differences in interpretation was the vagueness of the term "tundra". Only during the nineteen-thirties did the study of the tundra in Russia become established as a special branch of geobotany. Since then there has been so much progress in the theory of classification, the terminology of vegetation units (Sukachev, Shennikov, Lavrenko, Sochava, Ilynsky, and others), and the taxonomy of the arctic vegetation constituting them that the question as to what types of vegetation occur in Novaya Zemlya is much more amenable to correct solution.

There are three types of vegetation units in the South Island of Novaya Zemlya: tundra, bog, and polar desert. There is also some feebly developed aquatic shore vegetation consisting of stands of *Arctophila fulva* and *Hippuris vulgaris*. The submersed vegetation consists almost exclusively of algae (Flerov 1925) and mosses *(Drepanocladus exannulatus, Calliergon sarmentosum,* and *Sphagnum squarrosum)* occur only rarely (Fig. 1).

The principal zonal type (the "climatic climax") of vegetation is the tundra that has developed in upland areas. The author considers as tundra those communities on mineral substrata that are composed predominantly of mosses, fruticose and foliaceous lichens, arcto-alpine dwarf shrubs, and herbaceous perennial xero- and meso-microthermophytes (it can be said that all plants of the South Island of Novaya Zemlya are microthermophytes on account of its cold soils. They can be subdivided according to their moisture requirements into xero-, meso-, and hydro-microthermophytes. In addition there is a group of halophytic microthermophytes).

The areas of tundra are accompanied by bogs that develop in the wettest sites (azonal type of vegetation, the "subclimax"). To the bogs belong those plant communities that develop on a peat substratum. Their chief constituents are mosses and perennial herbaceous hydro-microthermophytes, and more rarely (on low peat mounds) also lichens and dwarf shrubs (Fig. 2).

The third type of community is that of the polar desert. It is extrazonal ("preclimax") in the South Island of Novaya Zemlya. It never occurs under normal (average) conditions in the upland areas, only either in wind-swept areas that have a very thin snow cover or at high altitudes in the mountains.

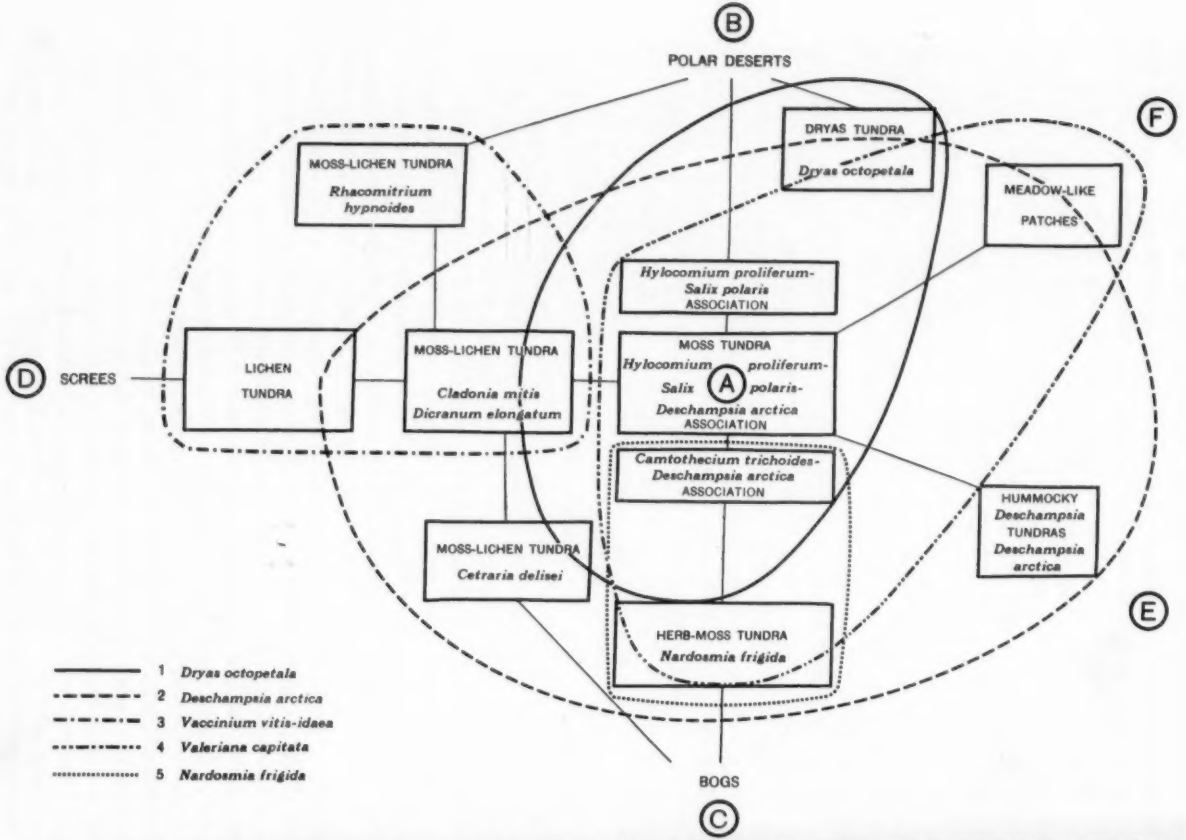

Fig. 3. Diagram showing the ecological ranges of the tundra plant associations and the ecological areas occupied by some plants.
Note: for *Camtothecium* read *Camptothecium*.

To the polar desert communities belong (Aleksandrova 1956) the micro-communities composed of crustaceous lichens, patches of mosses (*Rhacomitrium hypnoides, Dicranoweisia crispula, Grimmia apocarpa, Andreaea petrophila*, etc.), the representatives of some other tundra species that grow as widely scattered individuals, and the fragments of tundra communities that are confined to the depressions of the microrelief.

The plant communities of the arctic tundra subzone are here near the ecological limit of their distribution. Only in the bogs is the plant cover closed. In the upland areas it is interspersed with patches or polygons of bare ground that occupy from 10 to 65 per cent of the surface. The moss or moss-lichen patches appear as bands that surround the polygons in the form of nets. Wherever even a slight deterioration occurs (through stronger denudation, increasing stone content of the soil, shortening of the growing period in snow patches, etc.) the continuity of the plant cover is destroyed and it finally disintegrates into separate patches.

Where conditions become most unfavourable a further change may be observed; the tundra communities disappear completely and are replaced by the scattered plants of areas of shattered rocks and of polar desert, plants that belong mostly to the crustaceous lichens. The loss of continuity of the plant cover is accompanied by a change in its structure, layers are no longer recognizable and the individual plants form a horizontal (one-layered) mosaic.

In the tundra communities of the upland regions two or three layers can usually be distinguished, a layer of moss, one of fruticose lichens, and one of herbaceous plants, or of a combination of these and dwarf shrubs. The layers are poorly developed and dwarfed, since the total height of the vegetation is not more than 10 to 20 cm. The upper herbaceous layer is very sparse and the horizontal mosaic is well developed. It is closely dependent on the distribution of the main constituents of the patterned ground (stone rings, stone stripes, etc.), and on the microrelief. The severer the environment the closer is the response of the vegetation to the slightest change in the microrelief. Because the high permafrost table impedes drainage, every slight depression leads to the formation of bog; on the elevated portions of the relief denudation factors find their fullest expression. The plant mosaic is best developed on stone polygons ("stone nets").

Correlating the various tundra formations of the South Island of Novaya Zemlya with environment factors and arranging them in a diagram (Fig. 3) it will be found that the centre should be allotted to the moss-tundra, which is best adapted to the climatic conditions and most typical of the upland areas with clayey soils (the "climatic climax" of the area). Its most characteristic association consists of the moss *Hylocomium proliferum*, the shrub *Salix polaris*, and the grass *Deschampsia arctica*.

Along the line A — B are shown the changes that occur when one moves to more open sites, where the denudation forces are stronger; these sites are drier and have a thinner snow cover. The trend is here to another type of vegetation, that of the polar desert.

Fig. 3. Diagram showing the ecological ranges of the tundra plant associations and the ecological areas occupied by some plants.
Note: for *Camtothecium* read *Camptothecium*.

The line A — C leads to wet, poorly drained sites with heavier snow cover. Along it the succession tends toward the development of bog.

The line A — D shows the effect of the increase of the rock content of the soil. With an increasing number of stones the vegetation type changes from moss tundra on clayey soil to the moss-lichen tundra on stony-clayey and patterned ground and finally to the vegetation on scree and rockslopes with a predominance of crustaceous lichens. When weathering of the screes and rocks takes place the succession is reversed (from D to A).

Along the line A — E the amount of solifluction increases and one finds a succession from moss tundra to hummocky *Deschampsia* tundra. This transition occurs when the water-logged clayey soil slides downhill and the continuity of the plant cover is destroyed. Under these conditions a more stable community is formed, consisting of tufts of *Deschampsia arctica* and mosses, which together cover about 50 per cent of the ground, with the grass accounting for two-fifths of the cover.

Along the line A — F are indicated the changes that are caused by lemming burrows and fox mounds (the "disclimax") leading eventually to the formation of meadow-like patches. The enriching of the soil with nitrogen stimulates the development of a dense cover of grasses and herbs at such spots (the "nival" meadow-like patches that develop in more southerly tundras on the sites of snow patches are absent from the South Island of Novaya Zemlya, where no closed plant cover can develop on snow patches on account of the drastically shortened growing period).

It is of interest to compare the author's scheme with those devised for other tundra areas. For the tundras of the Kolsky Peninsula, which are according to their origin closely related to forests, a scheme was proposed by Tsinzerling (1932). Sochava (1934) devised one for the Anabar tundras, which belong to the "typical" tundra subzone. In the author's scheme, which applies to the arctic tundra subzone, the differences between the chief environmental factors that are apparent in tundra and forest zones are still more clearly expressed than in that of Sochava.

Of the five principal factors mentioned above, which determine the ecological and lifezone range and the trend of succession in the arctic subzone, those of (1) denudation, (2) solifluction, and (3) manuring are the most localized. Those of bog formation and of stone content are more general. The first is common in all zones that have a humid climate, the second depends on the composition of the soil in the area. Comparing this scheme with those evolved for other tundra subzones or for the northern forests shows that crossing the boundary between the forest and tundra zones involves a change of the whole system of principal environmental factors governing the succession trends in the plant cover.

Because of the absence of heaths and the wide distribution of moss-spotted tundra and sedge-grass marshes on the plains of the South Island of Novaya Zemlya, the island belongs to the arctic tundra subzone. The northern boundary of this subzone may be drawn a little to the north of Matochkin Shar (Fig. 4).

Between the arctic tundra subzone and the arctic deserts proper lies a transitional subzone. It may be called the southern variant of the polar deserts and stretches as far as the Admiralteistva Peninsula. It contains glaciers but no ice-cap. Vegetation is colonizing the areas that have recently become ice-free or emerged from the sea. On the mountain slopes polygonal polar deserts predominate on ground covered with stone nets. Under more favourable local conditions patches of tundra communities occur as well as small areas of arctic mineral bogs (without a peat substratum) and remains of relict peat bogs.

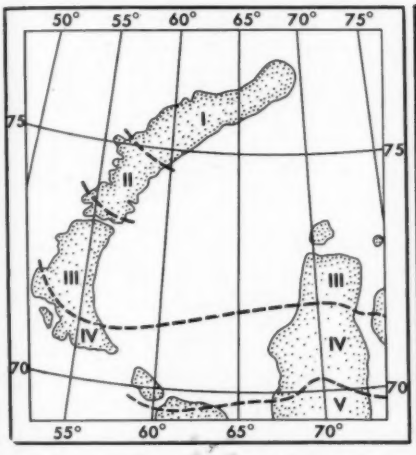

Fig. 4. Diagram showing the altitudinal zonation in the Novaya Zemlya area. I — the polar desert zone; II — the southern variant of the polar desert zone; III — the northern variant of the arctic tundra subzone; IV — the southern variant of the arctic tundra subzone; V — the subzone of the typical tundra.

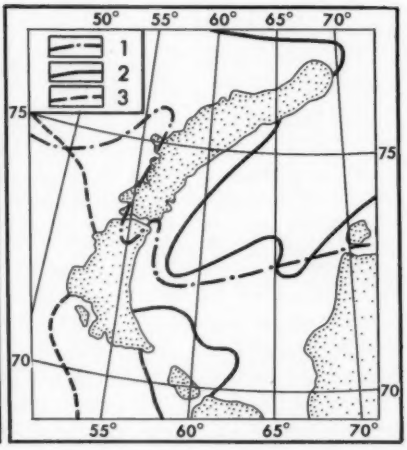

Fig. 5. The July isotherm of 5°C. and the limits of ice in the Novaya Zemlya area in July. (from Marine Atlas of the U.S.S.R., 1951). 1 — July isotherm of 5°C.; 2 — average limit of drift ice; 3 — extreme southern limit of drift ice.

To the north of the Admiralteistva Peninsula lies the polar desert zone proper. There vegetation is only found on the open ground outside the edge of the ice-cap. Plant associations of the tundra type hardly ever occur and there are only tiny fragments of moss and moss-lichen communities in little depressions of the microrelief and microcommunities of crustaceous lichens. Flowering plants are very rare and grow as single individuals. There are no accumulations of peat. The transition to the true polar desert is accompanied by an abrupt impoverishment of the flora. North of the 75th parallel only 79 species of vascular plants are found, whereas the southern part of the North Island has 148 species in the west and 141 species in the east, and the South Island 202 species (Tolmachev 1936). Thus the well-defined boundaries between phytogeographical, floristic, and physiographical zones coincide north of the Admiralteistva Peninsula.

In the arctic tundra subzone of Novaya Zemlya two distinct zonal variants can be clearly discerned, that is, a southern and a northern variant of the arctic tundra subzone. The boundary between the two can be drawn from Cape Severny Gussiny Noss (Northern Goose Nose Cape) southeast to the mouth of the Kumzha River.

The vegetation of the southern variant is distinguished from that of the northern by the predominance of moss-spotted tundras, great development of low-mound bogs, and the noticeable frequency of taller dwarf shrubs (*Salix reptans* and *S. lanata*) in the plant cover. This type of vegetation is to be found in the southwestern part of Gussinaya Zemlya (Goose Land) and on Mezhdusharsky Island.

To the northern variant of the arctic tundra subzone belongs the vegetation of the northeastern part of Gussinaya Zemlya and of the Kara Sea side of the island north of the Kumzha River. It is characterized by greater abundance of lichens, almost complete lack of low-mound bogs and great rarity of willows as tall as *Salix reptans;* only fully prostrate willows *(Salix polaris, S. arctica, S. reticulata,* etc.) grow there.

It is of interest to compare these subzone divisions with those that Andreev (1938) has distinguished in the northern part of the Yamal Peninsula. He called his two subzones of the arctic tundra (1) the "southern arctic tundra" subzone and (2) the "arctic tundra" subzone. Both differ from the more southern tundras in that they have been without trees for all post-glacial time, lack the shrub tundras, and show a preponderance of moss and lichen tundras and of arctic marshes. The transition from the "southern arctic tundra" subzone to the "arctic tundra" is indicated by the disappearance of even the oligotrophic and mesotrophic bogs and the increasing prevalence of tundras with very scant plant cover and an abundance of barren polygons. Andreev (1938) remarks that for his "arctic tundra" subzone "polygon moss and lichen tundras and polygon marshes are characteristic".

The changes in plant cover from north to south in Yamal Peninsula are the same as in Novaya Zemlya. Differences in the vegetation of the two areas depend chiefly on the amount of frost action. On the Yamal Peninsula frost cracks are well developed, but in Novaya Zemlya they occur only sporadically. High winter temperatures and deep snow cover inhibit formation of polygon marshes as well as of frost cracks in the moss-spotted tundras. Only in mountainous areas in the South Island of Novaya Zemlya can polygons be found in clayey soil and then only in places where no snow accumulates in winter owing to the winds. But in such places stony soils and not clay are more frequent and there not only the fine material but also small stones are blown away by the wind (Zubkov 1934). Therefore, frost cracks are rare even in the mountains. The origin of the bare spots in most parts of the tundras on the South Island, particularly in Gussinaya Zemlya and Mezhdusharsky Island is not connected with ice-wedge polygons and wind and snow erosion because the tundras are covered with deep snow

all winter (Aleksandrova 1937a, 1937b). The bare spots are caused by solifluction and by frost heaving, i.e., vertical movement of soil material due to the alternation of freezing and thawing. On the bogs the snow cover is very deep, in 1933 it was from 20 cm. to 130 cm., on an average 56 cm. deep (Aleksandrova 1937b). This, and the relatively high winter temperatures, explains why there are no frost cracks in the bogs and why marshes with polygons are absent. That the snow cover in spite of being compacted provides effective insulation is shown by the author's observations that in the middle of February the temperature under 80 cm. of snow was not lower than –3°C and later not lower than –9°C. (under 50 cm. to 80 cm. of snow it was –7°C. and –12°C. respectively).

Besides the climatic differences there are essential differences in geology, relief, and soil substratum between the South Island of Novaya Zemlya and the Yamal Peninsula. Consequently, Novaya Zemlya and Yamal Peninsula have been assigned to different phytogeographical provinces (Gorodkov 1935, Leskov 1947).

Furthermore, it should be pointed out that in Novaya Zemlya the boundaries between the vegetation subzones do not follow the parallels of latitude: in the west to east direction they are sharply deflected southward. This is a natural effect of the climatic differences between the Kara Sea side and the western side of the islands (Fig. 5).

During a floristic reconnaissance of the basins of the Rogatsheva, Savina, and Abrosimova rivers (Aleksandrova 1945) three altitudinal belts of vegetation were found. In the first belt (from sea-level to an altitude of 200 m.) chiefly alpine arctic tundras were found in areas where the ground contains sufficient clayey material and where the rocks weather into small particles; only under very unfavourable conditions is the vegetation of the open polar desert type. Bogs are here well developed.

In the second belt, the lower belt of alpine polar deserts (between 200 m. and 300 m. above sea-level), the rock and scree slopes either do not possess any vegetation at all or at most an extremely poor one. The surfaces of the rocks are covered with crustaceous lichens. Between the stones tiny cushions of mosses and single groups of lichens find shelter and there are scattered individuals of flowering plants. Alpine arctic tundras and small arctic bogs are to be found only under especially favourable conditions in well-sheltered situations. As a rule, the open vegetation of the alpine polar desert but not that of the tundra communities develops on ground that contains a sufficient amount of small particles of weathered rock.

The third zone is the upper belt of the alpine polar deserts (at altitudes greater than 300 m. above sea-level). On the central watershed of the mountain range there are no plant communities in the narrow sense of the term, except the microcommunities of crustaceous lichens. At the head of the Savina River there is hardly any vegetation on the rocky mountain tops or upper slopes. Crustaceous lichens grow on the surfaces of the rocks, and between the stones can be found scattered tiny depressed cushions of

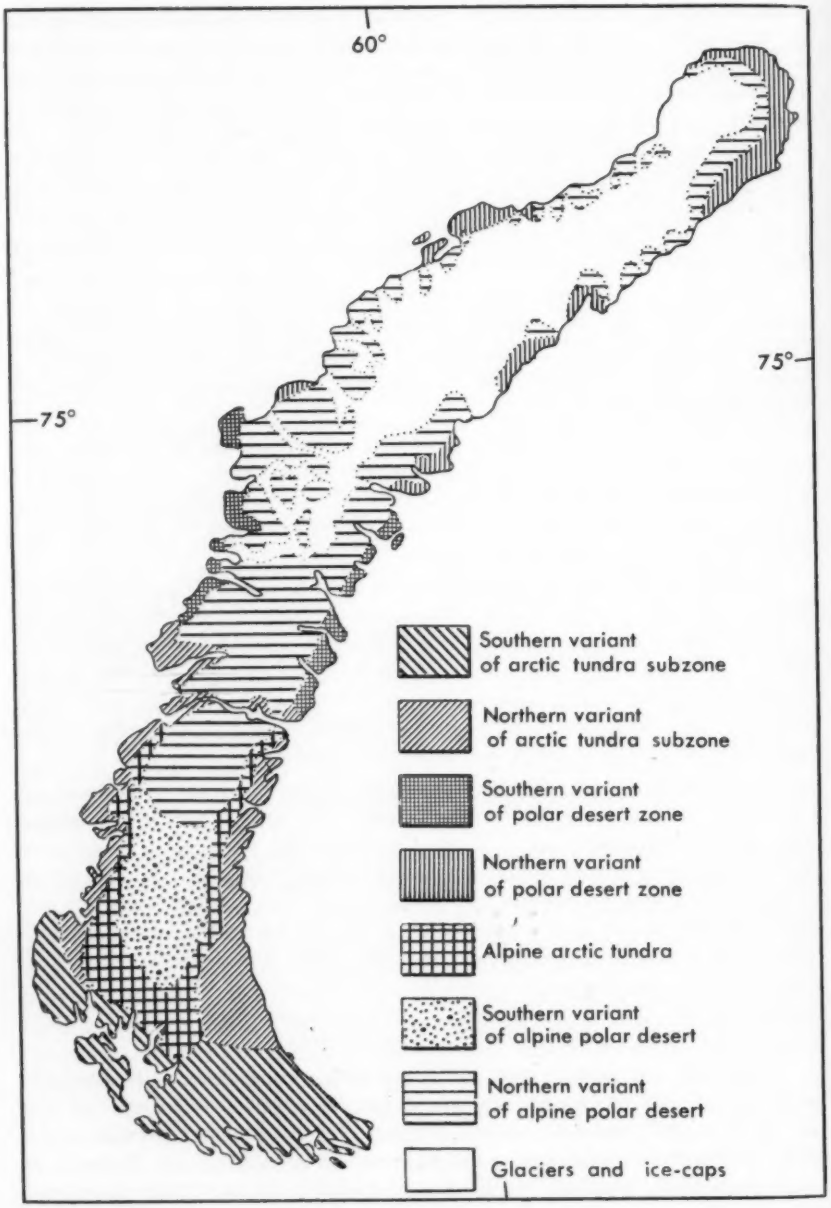
60°
75°
75°
Southern variant of arctic tundra subzone
Northern variant of arctic tundra subzone
Southern variant of polar desert zone
Northern variant of polar desert zone
Alpine arctic tundra
Southern variant of alpine polar desert
Northern variant of alpine polar desert
Glaciers and ice-caps

Fig. 6. Map showing the latitudinal and vertical zonation on Novaya Zemlya.

the mosses *Rhacomitrium hypnoides* and *Schistidium apocarpum* var. *glacialis* and single small individuals of *Stereocaulon* sp. On the lower parts of the slopes *Dicranoweisia crispula, Andreaea petrophila,* and single plants of *Cardamine bellidifolia* appear in addition to the above. Here and there on the bare scree slopes fragments of moss-lichen and herb-moss associations occur. On the gentle damp slopes of the wet clayey alluviums single small cushions of *Cetraria delisei,* isolated individuals of *Saxifraga rivularis,* dwarf tufts of *Phippsia algida* or *Deschampsia arctica* grow and all are very depauperate. The flowering plants, accompanied by few stems of a moss find shelter behind the features of the microrelief and have a miserable aspect. *Cerastium regelii,* for instance, has only two or four leaves and *Saxifraga cernua* is a dwarf not more than 3 to 4 cm. high.

The scheme of vertical zonation for the whole of Novaya Zemlya is presented in Fig. 6. The boundaries in the areas beyond that in which the author worked are based on Zubkov's data (Alexandrova and Zubkov 1937). The northern part of the North Island belongs into the northern variant of the polar deserts. It is still more impoverished than the southern one described above.

The investigations in the South Island of Novaya Zemlya have led to the recognition of the following regularities in the plant cover.

(1) In the arctic tundra subzone there are these types of vegetation: tundras, bogs, and polar deserts. In addition there is a feebly developed aquatic vegetation. Tundras occupy the upland sites and represent the vegetation characteristic of the zone (the "climatic climax"), bogs occur in wet situations (the "subclimax"); polar deserts are extrazonal (the "preclimax") and are either to be found in the mountains at high elevations or on the plains in certain localities, that is, in exposed sites where high winds prevent the formation of a snow cover (the "precursor" of the next, more northern vegetation zone of the polar deserts).

(2) The principal environmental factors that lead to trends in spatial changes of the vegetation (ecological ranges, changes along environmental gradients in space) as well as in chronological changes (successions) are (a) denudation, which increases with increasing exposure to wind action and the resulting decrease in snow depth; (b) accumulation of stagnant water in poorly drained situations, often accompanying deep snow cover; (c) the amount of stones in the soil; (d) solifluction; (e) manuring of the soil by animals. A comparison of the ecological ranges of the tundra associations in the arctic tundra subzone with that in the other tundra subzones and in the northern forest zone shows that the complex of principal environmental factors undergoes a complete change when one passes from a tundra to a northern forest zone.

(3) The arctic tundra subzone on the South Island of Novaya Zemlya, as well as on the northern part of the Yamal Peninsula (Andreev 1938) can be divided into two zonal subdivisions. The southern variant of the arctic tundra subzone is characterized by a noticeable element of willows as tall as *Salix reptans* in the plant cover of the moss-spotted tundras and by the

wide distribution of low-mound bogs. The northern variant is characterized by the scarcity of willows as tall as *reptans* (only the entirely prostrate species *Salix polaris, reticulata, arctica,* and others occur there), by the almost complete lack of low-mound bogs and by the prevalence of moss-sedge arctic marshes.

(4) The arctic tundra subzone in Novaya Zemlya can be divided into three belts according to altitude.

(a) The lower alpine belt (that of the alpine arctic tundras); it is characterized by the wide distribution of tundra and bog associations on suitable soils (soils that are sufficiently weathered and have a high content of fine particles).

(b) The intermediate alpine belt (= the lower belt of the alpine polar desert); there is found as a rule the open vegetation of the polar deserts on soils with a sufficiently high content of fine particles, but tundras and bogs occur only under specially favourable conditions.

(c) The upper alpine belt (= the upper belt of the alpine polar desert); there the tundra communities are absent, only fragments of them occur in sheltered depressions of the microrelief; accumulation of peat is completely suppressed, and the dominants of the bog communities disappear; only the open vegetation of the polar desert and the microcommunities of crustaceous lichens persist.

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THE DISTRIBUTION OF PERMAFROST AND ITS RELATION TO AIR TEMPERATURE IN CANADA AND THE U.S.S.R.

R. J. E. Brown*

Distribution and origin of permafrost

PERMAFROST is a widespread phenomenon in the northern parts of North America and Eurasia, and in Antarctica. Between 40 and 50 per cent of Canada's total land surface of 3.8 million square miles is underlain by permafrost. The total land area of the U.S.S.R. exceeds 8 million square miles of which 47 per cent is underlain by permafrost (Tsytovich 1958). Because of the great extent of this phenomenon knowledge of its distribution is of vital concern to both countries.

The distribution of permafrost varies from continuous in the north to discontinuous in the south. In the continuous zone permafrost occurs everywhere and is hundreds of feet thick. The continuous zone gives way to the discontinuous zone in which permafrost exists in combination with some areas of unfrozen material. The discontinuous zone is one of transition between continuous permafrost and ground having a mean temperature of above 32°F. In this zone permafrost may vary from a widespread distribution with isolated patches of unfrozen ground to predominantly thawed ground containing islands that remain frozen. In the southern area of this discontinuous zone (called the zone of sporadic permafrost in other countries) the permafrost occurs as scattered patches, is only a few feet thick, and has temperatures close to 32°F.

The thickness of permafrost varies with the locality; it is greatest in the Arctic and thins out near its southern limit. In Canada, at Resolute, Cornwallis Island, N.W.T., it is thought to be about 1,280 feet thick (Misener 1955); at Norman Wells, N.W.T. it is about 150 feet thick, and at Hay River, N.W.T. it is only 5 feet thick. In the U.S.S.R. permafrost exceeds 500 metres (1650 feet) in thickness in the Taymyr Peninsula. In southeastern and southwestern Siberia it is less than 25 metres (83 feet) thick (Tsytovich 1958).

The origin of permafrost is not well understood, but it is suspected that it first appeared during the cold periods of the Pleistocene. During the subsequent periods of climatic fluctuations corresponding changes must have

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occurred in the areal extent and thickness of permafrost. As a result it is now degrading in some areas and aggrading in others. For example, Russian workers report that the present southern limit of permafrost in the vicinity of the Yenisey River is many miles north of where it was a century ago. They report also that it is forming under the influence of the present severe climate in some of the recently built-up river islands and bars in northern Siberia (Muller 1945).

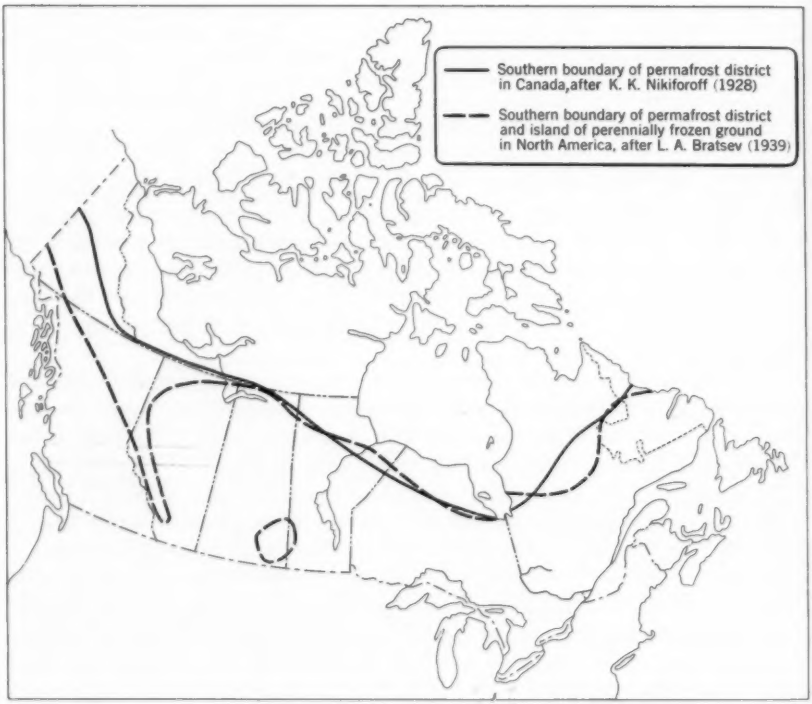
Southern boundary of permafrost district in Canada, after K. K. Nikiforoff (1928)
Southern boundary of permafrost district and island of perennially frozen ground in North America, after L. A. Bratsev (1939)

Fig. 1. Southern boundary of permafrost in Canada. After Nikiforoff (solid line), and Bratsev (dashed line).

Permafrost maps of Canada to 1953

The first map of permafrost in Canada and the northern hemisphere (Nikiforoff 1928) showed the southern limit as a single line (Fig. 1). In the light of present knowledge it contains many errors. In the Yukon Territory the line is far north of the southern limit of permafrost as it is known now. In Ontario just west of James Bay and in western Ungava the line is far south of bodies of discontinuous permafrost.

Bratsev drew a map in 1939 (Sumgin *et al.* 1940) showing the "southern boundary of the permafrost district and island of perennially frozen ground in North America" (Fig. 1). This is the earliest known attempt to indicate the presence of permafrost in the Cordillera caused by altitude. As on Nikiforoff's map permafrost is shown in Ontario and western Ungava south of the known occurrences. A large island of permafrost is also shown in southeastern Saskatchewan.

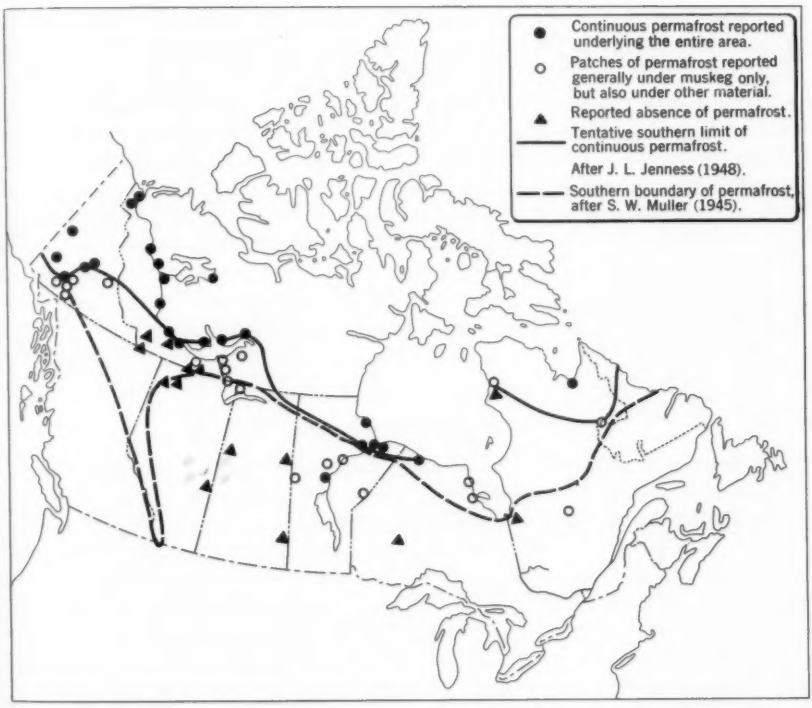
Continuous permafrost reported underlying the entire area.
Patches of permafrost reported generally under muskeg only, but also under other material.
Reported absence of permafrost.
Tentative southern limit of continuous permafrost.
After J. L. Jenness (1948).
Southern boundary of permafrost, after S. W. Muller (1945).

Fig. 2. Reports of permafrost and its tentative southern limit (solid line) after Jenness, and southern limit of permafrost (dashed line) after Muller.

The construction of the Alaska Highway and other wartime projects in the North stimulated North American interest in permafrost. In 1945 S. W. Muller drew a map of its southern boundary in Canada (Fig. 2), which was similar to Bratsev's (Muller 1945). The most notable features in Muller's map are his extending the permafrost boundary in the Cordillera into the northern United States and the omission of the large island of permafrost in southeastern Saskatchewan.

The first Canadian map of permafrost distribution was produced by Jenness in 1949 (Fig. 2). This was the first attempt to base the mapping of

permafrost on field observations; it included the information from a questionnaire sent to northern settlements. His categories comprised continuous and sporadic permafrost. His "tentative southern limit of continuous permafrost" actually lies south of currently known areas of discontinuous permafrost in the Mackenzie River valley and in Ungava. The map did provide, however, a more realistic picture of permafrost distribution in Canada than previous maps. Jenness made no attempt to indicate the presence of permafrost at high altitudes in the Cordillera.

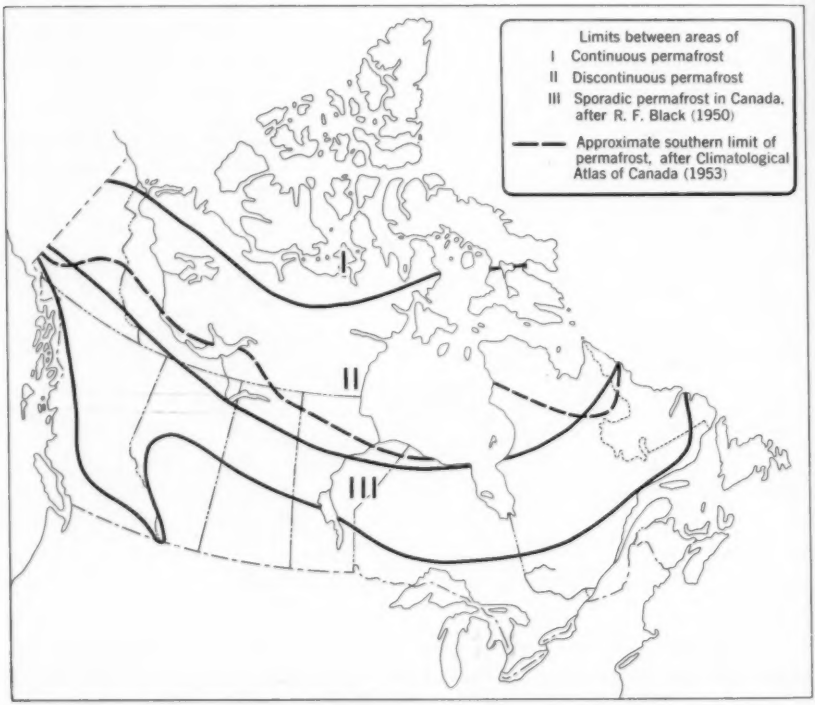
Limits between areas of
I Continuous permafrost
II Discontinuous permafrost
III Sporadic permafrost in Canada, after R. F. Black (1950)
Approximate southern limit of permafrost, after Climatological Atlas of Canada (1953)
I
II
III

Fig. 3. Zones of permafrost after Black, and approximate southern limit of permafrost after Climatological Atlas of Canada.

In 1950 a map of permafrost distribution by Black (Fig. 3) showed continuous, discontinuous, and sporadic occurrences in the northern hemisphere. In the preparation of his map Black used information from Russian maps to show the distribution of permafrost in Eurasia (Sumgin *et al.* 1940, Sumgin and Petrovskiy 1940). Black used the Russian ground temperature criteria to delineate the three zones that were based on the assumed temperature at

a depth of 10 to 15 metres (33 to 50 feet) in the vicinity of the depth of zero annual amplitude. This temperature must be less than -5°C. (23°F.) to be considered continuous permafrost, between -5° and -1°C. (23° and 30.2°F.) as discontinuous permafrost, and above -1°C. (30.2°F.) as sporadic permafrost. In the light of present knowledge the southern limit of continuous permafrost was drawn too far north, particularly in the Eastern Arctic and the southernmost limit was shown too far south.

In 1953 a map showing the "approximate southern limit of permafrost in Canada" (Fig. 3) was included in the Climatological Atlas of Canada published jointly by the Division of Building Research, National Research Council and the Meteorological Division, Department of Transport (Thomas 1953). The position of the southern limit coincided with that of Jenness, except at the eastern end of Great Slave Lake. The former map placed the area around the east end of the lake outside of the permafrost region and the latter included this area. Jenness called his line the "tentative southern limit of continuous permafrost" and the Climatological Atlas explained that it delineates a boundary north of which there are some areas free from permafrost, but of limited extent. This implies that it delineates the southern limit of discontinuous permafrost or that the area north of the line includes at least part of the discontinuous zone. The differences noted on these maps result from the sparsity of field observations of the areal extent and thickness of permafrost and of ground temperatures.

Russian Permafrost mapping

Russian expeditions have made detailed field observations of permafrost in the U.S.S.R. Thousands of excavations, borings, and ground temperature observations have advanced knowledge of the areal extent and thickness of permafrost sufficient for the making of detailed maps.

Between 1927 and 1940 a series of maps of permafrost distribution in the U.S.S.R. was compiled by M. I. Sumgin. His map of 1940 (Sumgin *et al.* 1940, Sumgin and Petrovskiy 1940) divided the permafrost region into three zones on the basis of the proportion of frozen to thawed ground in each zone and the soil temperature at a depth of 10 to 15 metres (33 to 50 feet). The delineation of the three zones has been given above in the discussion of Black's map of 1950.

In 1946 V. F. Tumel' published a map of permafrost distribution in the U.S.S.R., which was more detailed than previous Russian maps (Tumel' 1946). His first category comprises areas that are not perennially frozen, but lie within the permafrost region. The second is the zone of individual islands of permafrost that do not exceed 15 metres (50 feet) in thickness and exist above the depth of the zone of zero annual amplitude of ground temperature. Because this permafrost is thin and its temperature throughout is near 0°C. (32°F.), it is particularly susceptible to degradation and aggradation and even total disappearance during short-term fluctuations of the mean annual temperature (during a few to several tens of years). The third is the zone

of discontinuous permafrost not exceeding 35 metres (116 feet) in thickness. Thawed areas occur, but frozen ground predominates and is older and more stable than that of the second zone. Finally Tumel' divides the continuous permafrost into five subzones having thicknesses of 60, 120, 250, 500, and over 500 metres (200, 400, 825, 1650, and over 1650 feet). Very few taliks (unfrozen islands) occur and the permafrost is of great age. Tumel' showed also the location of the -1°, -3°, -5°, and -10°C. (30.2°, 26.6°, 23°, and 14°F.) ground isotherms at a depth of 10 metres (33 feet).

The most recent map of permafrost distribution in the U.S.S.R. was compiled by I. Y. Baranov in 1956 (Tsytovich 1958) and is shown in Fig. 4. In addition to the isopleths of thicknesses of permafrost shown on the map, ground temperatures in the permafrost at the depth of zero annual amplitude were shown by isotherms at intervals of 1 degree from 0° to -10°C. (32° to 14°F.). The presence of permafrost under the Arctic Ocean was also indicated.

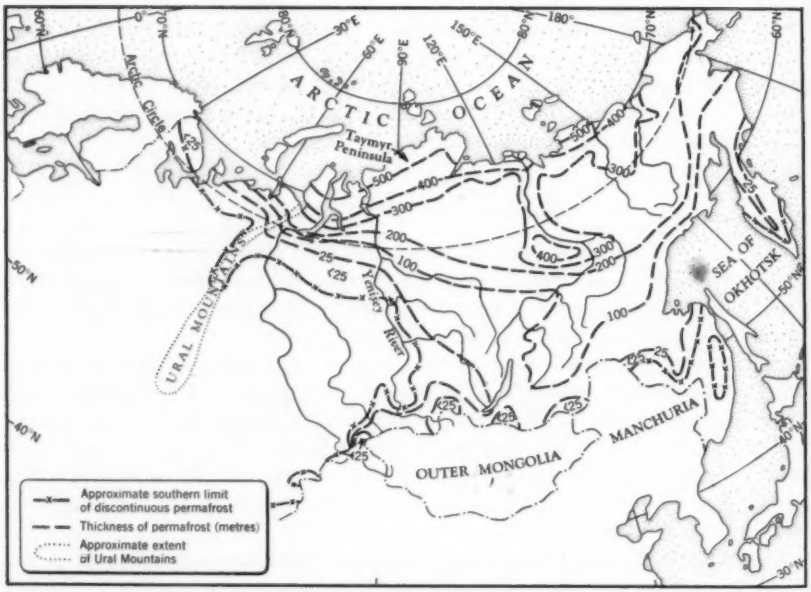

Fig. 4. Distribution of permafrost in the U.S.S.R. (After Baranov).

Current Canadian permafrost mapping

Since 1953 the Division of Building Research has been investigating the distribution of permafrost in Canada. Information has been gathered from a variety of sources, including the technical literature, reports from others

operating in permafrost areas, and by direct field observations. Emphasis has been placed on the determination of the southern limit of permafrost, but observations from the entire permafrost region are also being recorded.

For the purposes of compiling a permafrost map observations have been divided into four categories. The first two are continuous and discontinuous permafrost as defined at the beginning of this paper. The third category includes all conflicting reports from the southern areas of the permafrost region. In these localities permafrost has been reported, but is often suspected to be only seasonal frost, which may persist over a period of two or three years and then disappear, or the observation was made early in the summer before the ground had thawed to its maximum depth. Sometimes one observer reported "permafrost" and another reported "no permafrost" at the same locality. The fourth category includes all observations reporting no permafrost.

Each category has been given a symbol and the recorded observations have been plotted on the map of Canada. Following this the approximate delimitation of permafrost into two zones — continuous and discontinuous — has been attempted (Fig. 5).

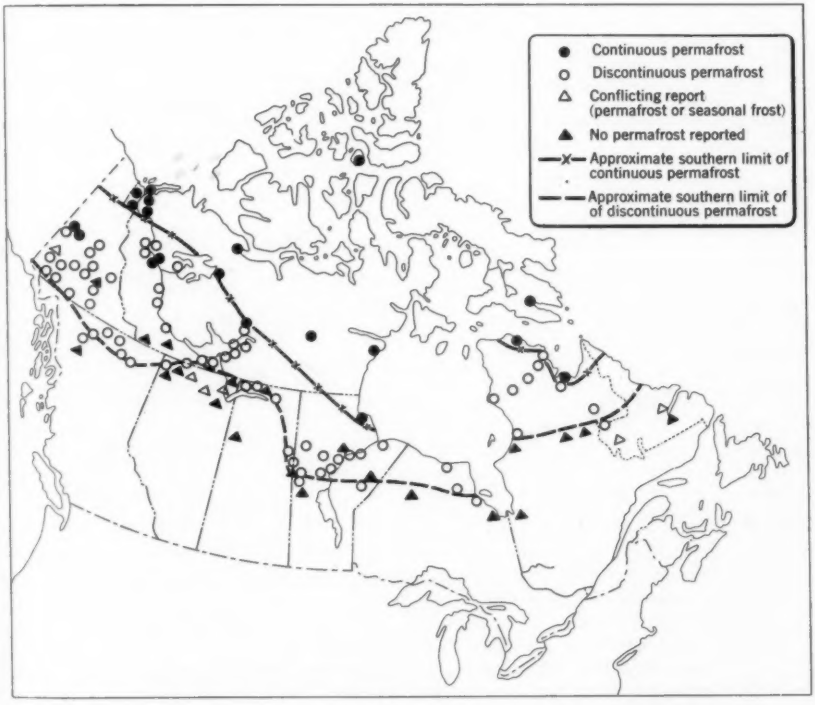
Continuous permafrost
Discontinuous permafrost
Conflicting report (permafrost or seasonal frost)
No permafrost reported
Approximate southern limit of continuous permafrost
Approximate southern limit of of discontinuous permafrost

Fig. 5. Distribution of permafrost in Canada (National Research Council, 1959).

Knowledge of permafrost distribution has been influenced by accessibility, so that the majority of observations lie on or near transportation routes. As a result there are parts of the country where information is extensive and others where it is very limited. A permafrost questionnaire has been prepared for distribution to settlements in northern Canada where permafrost is suspected or known to exist. It includes questions on vegetation, soils, depth of thaw, thickness, and areal distribution of permafrost. The answers to this questionnaire will provide information from new areas and supplement that already existing. The reliability of the information will depend on the observer and sometimes be of questionable value. The information will nevertheless indicate where future field observations should be made.

Ground temperature observations in Canada are scanty and therefore cannot be used to delimit the two permafrost zones, but some ground temperature records are available and are presented in Table 1 with information on the areal distribution and thickness of permafrost (see Fig. 6 for the location of ground temperature installations). More observations are required, however, before the distribution of permafrost can be mapped on the basis of thickness and temperature as has been done in the U.S.S.R.

Table 1. Mean ground temperatures in Canada's permafrost region (under natural cover)

Locality	*Length of observation period*	*Mean ground temp. °F.*	*Depth below ground surface feet*	*Thickness of permafrost feet*	*Areal distribution of permafrost*	*Mean annual air temp. °F.*
Schefferville[1] (Iron Mines)	summer	26–28 approx.	30	variable (less than 50 to approx. 200 ft.)	discontinuous (patchy)	21–22 (Iron Mines)
Kelsey[2]	1 year	30–31	10–20	variable	discontinuous (patchy)	25
Uranium City[2]	2½ years	31–32	—	variable (up to 30 ft.)	discontinuous (patchy)	22
Aishihik[4]	2 years	29.1 28.0	5 20	50–100	discontinuous? (wide-spread)	25
Yellowknife[5]	2 years	31.9 30.1	2.2 8.2	40–115	discontinuous (wide-spread)	22
Norman Wells[6]	summer	Hole No. 1 30.3 31.2 Hole No. 2 26.3 28.8	 50 100 50 100	 200 / 140	discontinuous? (wide-spread)	21
Churchill[7]	4 months	27.5 28.9	25 54	100–120	continuous?	19
Inuvik[8]	3 years	25.9	47	?	continuous	16
Resolute[9]	4 years	10 8.5	50 100	1300	continuous	3

[1]J. D. Ives, McGill Subarctic Res. Lab., Schefferville, P.Q. (Personal Communication).
[2, 3]Div. of Buildg. Res., Natl. Res. Counc., Ottawa.
[4] Meteor Div., Can. Dept. of Transport.
[5, 6]Div. of Buildg. Res., Natl. Res. Counc., Ottawa.
[7]J. R. Lange, S.I.P.R.E., Wilmette, Ill., U.S.A. (Personal communication).
[8]Div. of Buildg. Res., Natl. Res. Counc., Ottawa.
[9]Misener, A. D. 1955. Trans. Am. Geophys. U. 36: 1055–60.

Permafrost distribution and air temperature

Many investigators have made estimates of what mean annual air temperature is required to produce and maintain a perennially frozen condition in the ground, but there is much disagreement on this matter. One investigator reported that the southern limit of permafrost coincides very roughly with the 0°C. (32°F.) mean annual isotherm (Terzaghi 1952). In Canada this certainly does not hold true, because this isotherm lies a considerable distance south of known areas of discontinuous permafrost. Another investigator reported that the mean annual air temperature required to produce permafrost varies many degrees because of local conditions and suggested that it is generally between 24°F. and 30°F. (Black 1950). In a climatic hypothesis of the origin of permafrost is was suggested that the southern boundary coincides approximately with the –2°C. (28.4°F.) isotherm (Nikiforoff 1928).

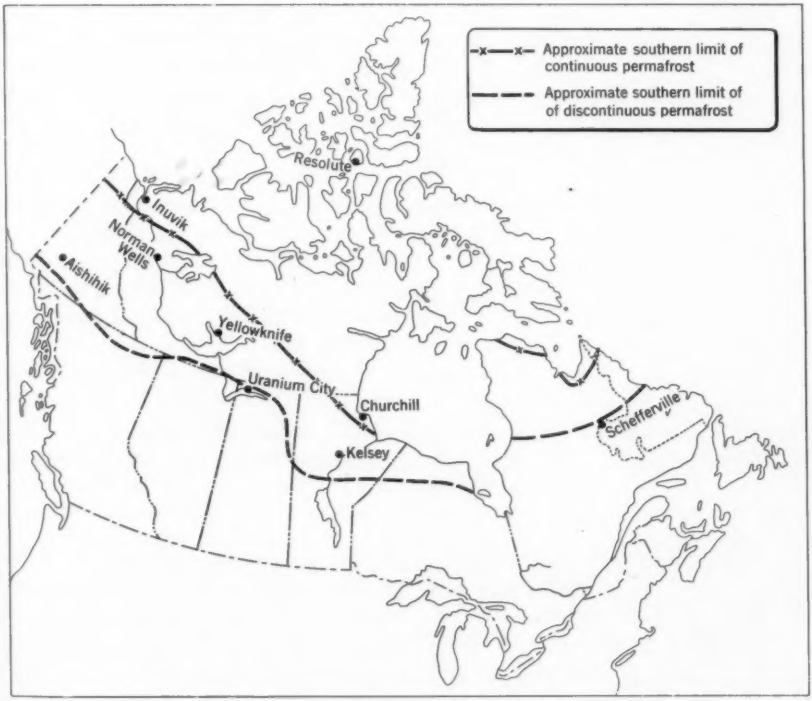

Fig. 6. Locations of ground temperature installations.

West of Hudson Bay there is some similarity between the position of the 25°F. mean annual isotherm and the southern limit of permafrost (Figs. 6 and 7). In the Yukon Territory, however, the 30°F. isotherm lies much nearer the approximate southern limit. In Manitoba the known limit of permafrost cuts diagonally from the 25°F. to the 30°F. isotherm. In Ungava the permafrost limit lies far north of the 25°F. isotherm, but in Labrador there appears to be some coincidence between this isotherm and the permafrost limit.

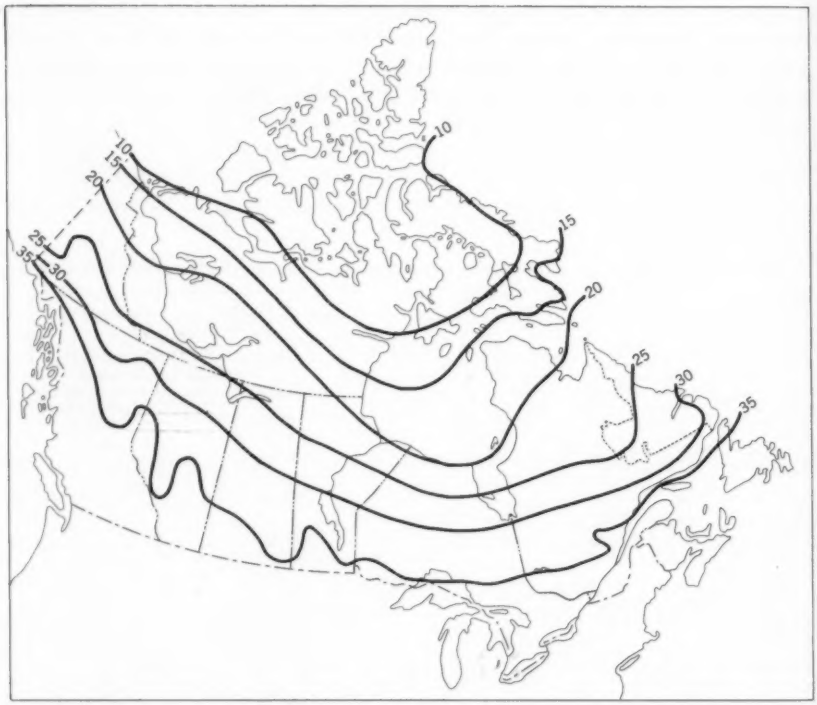

Fig. 7. Mean annual air temperatures. (°F.) Prepared by National Research Council and Canada Department of Transport.

The southernmost occurrence of permafrost reported to date in North America lies on the west shore of James Bay at about 53°N. East and west of there its southern limit lies farther north. In Asia the southernmost occurrence of permafrost lies in Manchuria and Outer Mongolia at 48°N., about 350 miles farther to the south than in Canada. This situation is analogous to the geographic location of isopleths of the number of months in the year during which the ground remains frozen at various depths. Three maps

show the duration of frozen ground at depths of 10, 30, and 120 centimetres (4, 12, and 48 inches) in the northern hemisphere (Chang 1958). The line for the 5-month isopleth at the 120-centimetre (48-inch) depth is shown in southern Alaska at 60°N. from where it extends in a northeasterly direction to northern Baffin Island at 73°N. In Asia the same line corresponds more or less to the southern limit of permafrost and extends southward to nearly 45°N. The same pattern holds for all three of Chang's maps.

It is interesting that the isotherm for the mean annual temperature of –2°C. (28.4°F.) lies south of the permafrost boundary in most of Canada, whereas in the U.S.S.R. it lies considerably south of the permafrost boundary only in western Siberia. East of the Yenisey River the southern boundary runs almost due south across this isotherm into Mongolia and does not recross it until just inland from the Sea of Okhotsk. Thus a large part of southern Siberia, northern Outer Mongolia, and Manchuria lies south of the –2°C. (28.4°F.) isotherm and north of the permafrost boundary. The permafrost in this area is patchy and lies so deep that it is not in equilibrium with the present climate and must be a relict of a former colder climate. The same situation may have existed in Canada.

Several factors may cause the permafrost to extend so far south in eastern Asia. The land mass is much larger than in North America, resulting in a more continental climate. The high pressure system over Siberia in winter and the numerous mountain ranges near the coast effectively prevent Pacific disturbances from moving inland. In July the mean monthly air temperatures are about the same as in northern Canada. In January the mean monthly temperatures are 20° to 30°F. lower. This means similar thawing indices in both regions, but much higher freezing indices, and conditions are thus more favourable for permafrost to form and persist than in northern Canada.

Attempts have been made in Canada to relate permafrost distribution and freezing indices. The freezing index for any locality is the yearly sum of the differences between 32°F. and the daily mean temperature of the days with means below 32°F. In 1954 a freezing index map of Canada using mean daily temperatures for the 10-year period 1941 to 1950 was compiled (Wilkins and Dujay 1954). The map (Fig. 8) shows a similarity in the position of the 5500 degree-day freezing index and the southern limit of discontinuous permafrost from the western Mackenzie District to the Manitoba-Ontario border. In the Yukon Territory and in Labrador-Ungava, however, there is no correspondence.

Because the development and persistence of permafrost is also related to the thawing of the ground it is necessary to consider thawing indices as well (Fig. 9). The thawing index is the yearly sum of the differences between 32°F. and the daily mean temperature of the days with means above 32°F. Taking the freezing index as negative the algebraic sum of the thawing and freezing indices divided by the number of days in the year equals the departure of the mean annual temperature from 32°F. Therefore a station with high freezing and thawing indices can have the same mean annual temperature as a station with low freezing and thawing indices.

A station with a high freezing index should have permafrost if its thawing index is low. If its thawing index is high, as in the interior of the continent where the climate is extreme, then summer heating will counteract winter cooling and the formation of permafrost is inhibited. Similarly, a station with a low freezing index can have permafrost if its thawing index is also low, as in maritime localities. This is well shown in Canada by the location of the

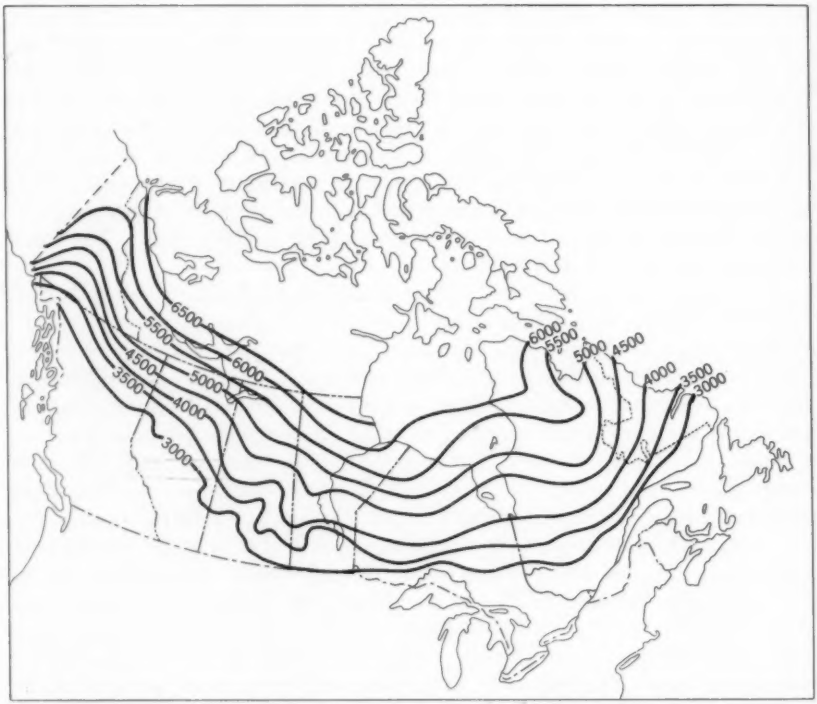

Fig. 8. Freezing indices. Averages for the 10-year period 1941-50. (Wilkins and Dujay. Meteorological Division, Canada Department of Transport).

3500 degree-day freezing index isopleth. In Fig. 8 this isopleth lies in the southern Yukon Territory where thawing indices are near 3000 and where there is discontinuous permafrost. In central Canada it lies in the neighbourhood of Regina, Sask., Winnipeg, Man., Lake Nipigon, and Lake Abitibi, where thawing indices exceed 4000 and the southern limit of discontinuous permafrost is hundreds of miles to the north. In Labrador, however, it swings northeast to Goose Bay, where the thawing index is about 3200 and the southern limit of permafrost is not many miles distant. The same trend holds true for other freezing index isopleths.

A marked discrepancy between permafrost distribution and the air temperature regime occurs around Hudson Bay and James Bay. Examination of the annual air temperature map (Fig. 7) reveals that the 30°F. and 25°F. isotherms coincide approximately with the parallels of 51°N. and 53°N. respectively, for a distance of several hundred miles east and west of James Bay, and the 20°F. isotherm follows the coastline of Hudson Bay from Churchill, Man. to a point between Great Whale River and Port Harrison, P.Q.

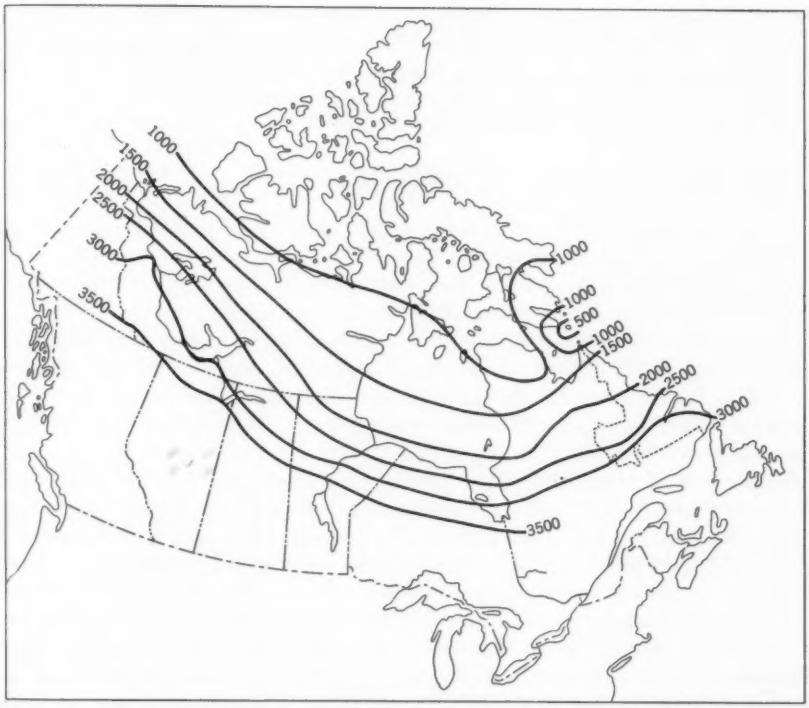

Fig. 9. Thawing indices from mean monthly temperatures (Division of Building Research, National Research Council, 1959).

The southern limit of permafrost, which is marked by the occurrence of palsas with perennially frozen cores (Hustich 1957-8), does not follow this pattern, but lies much farther south on the west side of Hudson Bay than on the east side. Palsas occur along the Attawapiskat River in Ontario at 53°N. (Sjörs 1959). On the east coast of Hudson Bay the most southerly occurrence of palsas exists at 55°20′N. near Great Whale River, nearly 200 miles farther north than that at the Attawapiskat River (personal communication from G. B. Faulkner, Dept. of Mines and Technical Surveys, Ottawa).

Farther east in the centre of the Labrador-Ungava Peninsula permafrost has been encountered as far south as 53°N., but only at elevations close to 3000 feet.

The marked difference in latitude of the most southerly occurrence of palsas with perennially frozen cores on the east and west sides of Hudson Bay and James Bay is caused probably by some other factor than air temperature. Hudson Bay seems to have an appreciable effect on the amount of snowfall over the region immediately east of it, especially in the fall and early winter. Examination of the snowfall records and maps (Thomas 1953) reveals that the snowfall in October to December totals about 60 inches on the east side and only 40 inches on the west side. The insulation provided may help to explain the apparent discrepancy and the conspicuous jump northward of the two permafrost zones in crossing the bays.

Conclusion

It is evident that there is not a close relationship between permafrost distribution and air temperature. Because so many factors — climatic, surface, and geothermal — affect the occurrence of permafrost prediction of its distribution cannot be based solely on this one climatic factor. Nevertheless, examination of the southern limit of permafrost as known at present and of air temperature pattern reveals the existence of a very broad relationship.

The mapping of the distribution and the delineation of the southern limit of permafrost is a problem with many aspects. What defines the southern boundary and how can it best be shown cartographically? Does a pereletok (a shallow spot of frozen ground that persists for several years), which persists for a number of years and then disappears, belong to the permafrost? How many years must a pereletok persist to be classed perennially frozen ground? Can relict permafrost be distinguished from a pereletok in the field? These and other problems make it difficult to locate the southern limit of permafrost.

A large number of field investigations of permafrost and observations of ground temperature are required to give detailed knowledge of its areal distribution and thickness for mapping purposes. In Canada this work is still in the early stages, but already the general areal distribution of the two permafrost zones is becoming evident.

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MAXIMUM POST-GLACIAL MARINE SUBMERGENCE IN NORTHERN MELVILLE PENINSULA*

Victor W. Sim

Introduction

LITTLE quantitative work has so far been done to determine the limits of marine submergence in arctic Canada. Until the last decade scattered altitudes obtained by early travellers were all that was available for large areas. In 1947, however, Washburn (1947, p. 61 ff.) collected all available information for the western Arctic and by combining it with his own observations presented the first unified account of arctic regional uplift. Since then the work of Bird has been noteworthy in the central and eastern Arctic. His studies in Southampton Island (1953), Bathurst Inlet (1955), and in the central Arctic as a whole (1954) have been particularly valuable. The present paper, based on observations made during the field seasons of 1957 and 1958, provides similar information for the northern part of Melville Peninsula, N.W.T. (Fig. 1).

Most contemporary geophysicists subscribe to the theory that a continental ice mass exceeding a certain minimum size in area and thickness will depress the crust of the earth by elastic compression and plastic deformation. When the weight of the ice is removed with deglaciation the crust will rebound nearly to its former position. Both Daly (1934, p. 135) and Gutenberg (1941, p. 752) considered that the amount of elastic compression was considerable. The former estimated it at 525 feet and the latter at 330 feet in North America. Mercer, however, has pointed out that the recovery from elastic compression takes place "if not theoretically instantaneously, actually as fast as the load is increased or decreased" (1954, p. 73). Gutenberg states (1941, p. 752): "fortunately we can disregard the elastic part of the uplift if we restrict ourselves to the time after the ice had disappeared. The movement, due to 'elastic afterworking' during the later period of the uplift was relatively small and may be included in the plastic uplift". Guilcher (1958, p. 46) in his discussion of glacial isostasy makes no mention of elastic compression, attributing the depression entirely to plastic deformation by "the slow flow of viscous material toward the periphery of the areas affected to re-establish an equilibrium".

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Since Melville Peninsula has probably not yet completely recovered from the weight of the recently melted ice cover, it is impossible to determine accurately the total crustal depression. Flint (1957, p. 242) has, however, expressed the opinion that crustal depression under an ice sheet should be roughly equivalent to one third of the total thickness of the ice. According to Daly (1938, p. 182) an ice cap must have a minimum thickness of 3300 feet and a minimum diameter of 300 miles before it will depress the crust at all. Since Melville Peninsula and Foxe Basin have undoubtedly been depressed and since the Pleistocene ice cap over Foxe Basin certainly exceeded the minimum figures, a crustal depression of at least 1100 feet seems probable. The amount of uplift in the peninsula to date has been approximately 450 feet (pp. 189-92). Assuming that crustal depression is a completely reversible process the crust should rise another 650 feet before equilibrium will have been re-established. This figure is in the same range as the amount of uplift still to be expected in the Hudson Bay region (Gutenberg, 1941, p. 766).

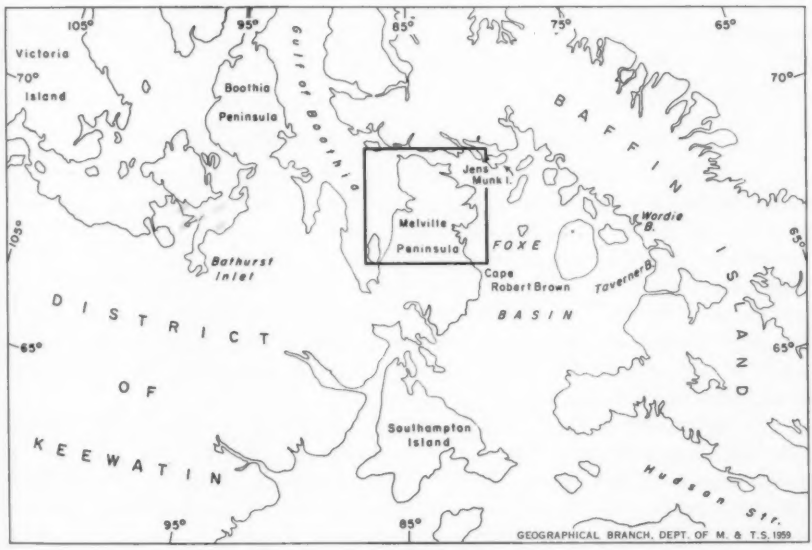

Fig. 1. Location map of Melville Peninsula.

Tide gauge records at Churchill, Manitoba (Gutenberg, 1941, p. 747) indicate that the shores of Hudson Bay are rising at a rate of 3 to 6 feet per century. Blackadar (1958, p. 164) using Meldgaard's archaeological data has recently determined a possible rise of 4.5 feet per century at Igloolik. The relatively shallow Foxe Basin — nowhere north of Cape Robert Brown do depths exceed 50 fathoms — may therefore be expected

to become a broad flat plain drained by a major south-flowing stream in 6000 to 7000 years. Even at that time emergence will not be complete.

Soon after the ice cover over Melville Peninsula started to melt, the land began to rise. Some movement almost certainly took place while ice still lay over the peninsula and Foxe Basin. This early rise could leave no record, however, until the ice margin had retreated sufficiently to allow sea water to inundate the land and start forming strandlines. Flint (1957, p. 244) states: "as there are no means of measuring the amount of this early recovery, the value of total measured recovery is a minimum and total actual recovery was greater than this by an unknown amount". Moreover, the return to the ocean basins of water that had been abstracted during glaciation to form the ice caps caused a eustatic rise in sea-level. The quantity of water released by this process is estimated to have been sufficient to raise sea-level by amounts ranging from 275 to 390 feet (Flint, 1957, p. 260). Most of this rise had however taken place before isostatic recovery began in the area of Melville Peninsula. Since the figure for maximum submergence can only be related to the contemporary sea-level it must be remembered that the actual amount of recovery is too small by the amount of the eustatic rise in sea-level plus the amount of the early and unrecorded isostatic rise. There seems to be no way to measure either of these quantities.

Determining the limits of marine submergence

For Melville Peninsula a cursory examination of the air photographs of the eastern area is sufficient to indicate that the land has been submerged. Rows of well-developed parallel strand-lines rise inland to the westward across the eastern lowland. In the field the presence of unbroken marine shells on the ground at an altitude exceeding 200 feet also indicates submergence. Finally, former Eskimo camps, normally built near sea-level, are often found at altitudes considerably above this. Boulder tent rings, meat caches, whale and walrus skeletons, and occasional artifacts have been found at heights approaching 200 feet.

In determining the actual limits of post-glacial marine submergence the following four main criteria were used: (1) the highest altitude at which marine shells occur, (2) the highest altitude at which strand-lines are preserved, (3) the lowest altitude at which undisturbed ground moraines can be recognized, (4) the lowest altitude at which perched boulders are found.

Marine shells

Marine shells are common in raised deposits on the gently shelving east coast of the peninsula. They occur less frequently on the more rugged west coast where the conditions near the shore of a high-level sea did not provide a suitable environment for them. Wherever they are found unbroken and in considerable numbers, however, they may be taken to indicate submergence. The highest altitude at which shells are found is

generally considered to mark the marine limit. However, many of the species found above sea-level today still live in coastal waters in the Arctic and it is known that at present they find their most favourable environment at a considerable depth below sea-level. Thus the altitude of the highest shells can only be taken as a minimum figure for the marine limit.

The collections of marine shells made during the summers of 1957 and 1958 were examined by Dr. F. J. E. Wagner of the Stratigraphic Palaeontology Section, Geological Survey of Canada. The species identified have been recorded in G.S.C. Report No. PL 6/57/58.

Of the several classes of mollusc that are known to occur above present sea-level in the Arctic, the pelecypods are most common. Three species were especially numerous in Melville Peninsula. *Hiatella arctica* Linné (= *Saxicava arctica)* was frequently found. This species has been cited by MacGinitie (1955, p. 174) as the most abundant bivalve in the coastal waters at Point Barrow, Alaska, where it is most numerous at depths below 110 feet. It has a very wide ecological tolerance, having been observed in Alaska attached to boulders at a depth of only a few feet near the shore. This wide range may explain why this shell was frequently the highest species found in any locality. It was noted near the summits of several of the islands in Garry Bay at altitudes over 300 feet and was found at similar altitudes in the hills north and south of the Kingora River.

Macoma calcarea Guelin, the second most common species at Point Barrow (MacGinitie, 1955, p. 174), was taken there at depths averaging 70 feet. It was less common in Melville Peninsula but was found, often with the shell still hinged, in recently emerged stratified sands.

The only other mollusc that deserves mention is *Mya truncata* Linné. This species, not common at Point Barrow, occurred widely in Melville Peninsula. It was found in Alaska at depths ranging from 122 feet to 477 feet. South of Amherst Island on the Melville mainland it was found at an altitude of over 400 feet near the limit of submergence.

Other pelecypods that were noted at altitudes above present sea-level include *Astarte borealis* Schumacher, *Clinocardium ciliatum* Fabricius and *Serripes groenlandicus* Bruguière. All these species were found by MacGinitie (1955, p. 173) to be most common at depths exceeding 80 feet. Gastropods occur infrequently in raised marine deposits. One species, *Colus* sp., did occur in considerable numbers at the mouth of Hall River.

Two of the three principal molluscs found in Melville Peninsula live normally at depths exceeding 70 feet. The less common species prefer depths greater than 80 feet. Only *Hiatella arctica* can be expected to occur in shallow water and even this species has a marked preference for deeper water. Any particular shell of this species found above present sea-level probably lived within the normal range for the species. It is not surprising, therefore, that the use of marine shells to determine the limit of marine submergence commonly gives a result considerably lower than that yielded by other criteria. In effect the highest marine shell may mark an altitude at least 70 feet, possibly 100 feet, lower than the actual marine limit.

It may be argued that the highest marine shells are those that have been washed up on shore during storms when the sea stood at its maximum elevation. Since the natural environment of the molluscs is considerably below the limit of normal wave action it is probable that the number of shells deposited in this way was small. Those that were deposited would be quickly destroyed by subsequent wave action or by weathering in their exposed positions. Shells, moreover, are extremely rare in the tidal zone or on storm ridges along the modern shore of the peninsula.

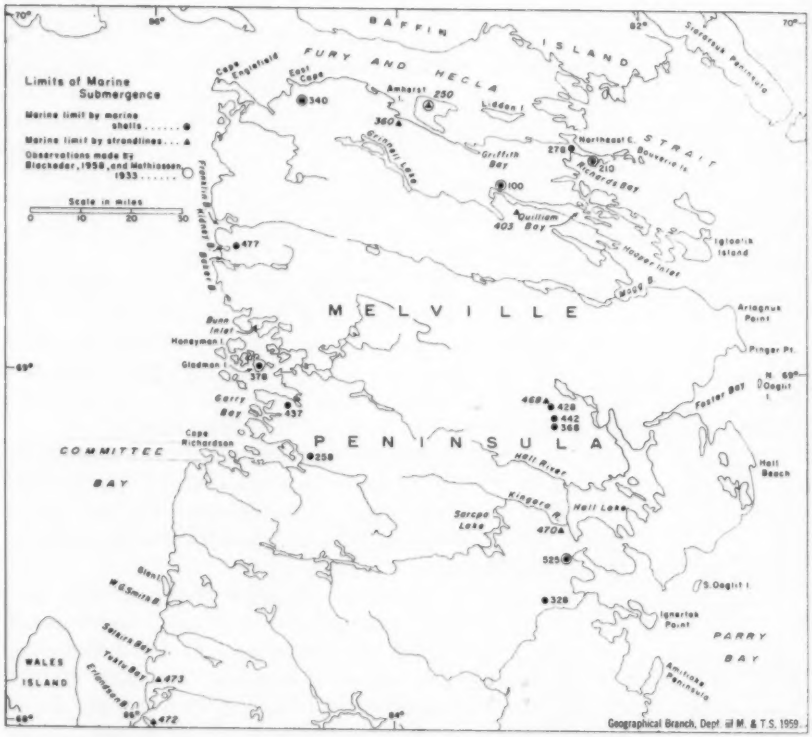

Fig. 2. Map showing locations and altitudes of marine shells and strand-lines.

In general, shells were found to have only limited value in determining the marine limit. On the west coast where the land rises steeply shells are at first numerous, but decrease rapidly in number with increasing altitude and often could not be found above 200 feet. Even on the gently rising east coast diligent search was required to find shells at higher altitudes. The highest marine shell discovered was at an elevation of 477 feet. A mean value for the limit of submergence determined by this method is 404 feet. Locations and altitudes of the highest shells are shown on Fig. 2.

Strand-lines

Raised strand-lines are found widely distributed in all coastal areas of Melville Peninsula, but are most numerous on the eastern limestone lowland. They are less common on the north and west coasts, but are well developed on Wales Island and on the headlands at the mouth of Franklin and Baker Bays. Here and there on steeply rising Precambrian coasts uninterrupted series of bayhead cobble beaches rise in step-like arrangement for short distances above present sea-level. In these locations no major interruptions are visible in the closely spaced strand-lines and this suggests continuous emergence.

Features resembling strand-lines found at high levels must be interpreted with caution as indicators of the marine limit because as Bird points out (1953, p. 21) they may in fact be lateral moraines, river terraces, or other fluvio-glacial forms. For example, pockets of water-worn pebbles and sand found at considerable altitudes may be of marine origin or they may equally well be glacial stream deposits.

Strand-lines are found most often at altitudes close to present sea-level. Their number and state of preservation decrease with increasing altitude. The higher and older strand-lines have been exposed longer to subaerial erosion than lower ones and have been largely destroyed. For this reason the criterion of raised strand-lines was seldom of value in determining the limit of marine submergence. However, where present, strand-lines yielded results that varied little from those deduced from undisturbed ground moraine and perched boulders. The mean altitude for the marine limit in northern Melville Peninsula determined by strand-lines is 440 feet. Altitudes for the limit determined in this way have been plotted on Fig. 2.

Undisturbed ground moraine

The lowest limit of undisturbed ground moraine may be taken to mark the highest level of the sea. The method of using this criterion first suggested by Daly (1902, p. 258), has been described by Bird (1953, p. 21) and applied by him on Southampton Island. For Melville Peninsula it may be summarized as follows: after the melting of the ice sheet the land surface was covered with a veneer of bouldery ground moraine of variable composition. In some areas this moraine consists of a scattered layer of large boulders on a bare rock surface. Elsewhere it is a blanket of bouldery till several feet thick. Whatever its composition this material could not escape some degree of alteration by wave action in the post-glacial sea. The limit of this wave action is often visible on the land surface and its altitude can be determined.

Where the ground moraine consists of a scattered cover of boulders on a sloping Precambrian surface the area below the marine limit is often swept completely bare of boulders. Above this sharply defined region the boulders are undisturbed. Where the ground moraine is composed of glacial till the marine limit shows up equally well. In the material above the limit

Fig. 3. Boulder bench at the limit of marine submergence near Erlandson Bay, west coast of Melville Peninsula. Undisturbed ground moraine may be noted on the slope rising behind the bench.

Fig. 4. Terrain in foreground and hilltop in left background are veneered with undisturbed gro[und] the photograph and the terrain in the right background are below the limit of ma[rine]

there is an obviously heterogeneous mixture and the moraine has an "unsorted" appearance. Boulders often project with their long axes vertical

to the surface of the ground. The ground surface is irregular and resembles that of a solifluction lobe. Below the marine limit, which may be marked by a slight break in the slope or by a pronounced bench (Fig. 3) the material is visibly different. Here it has a partly sorted, waterwashed look. Minor surface irregularities have been removed and the boulders are solidly embedded in the moraine. Furthermore, the vegetation of grasses, arctic willow, avens and purple saxifrage often forms a more complete ground cover.

The distinction between previously submerged and unsubmerged ground moraine can be clearly seen, moreover, in a more general view of the landscape. Below the marine limit the terrain has a smoothed and softly contoured appearance. Hill tops may be bare rock knobs whereas the shoulders of the hills are covered with partially sorted till. Slopes are smooth and gently concave and the area has a "neat" appearance. Above the marine limit the ground surface is littered with boulders and cobbles. Ridges and hills have a serrated, irregular skyline and the appearance is "untidy" (Fig. 4).

Using undisturbed ground moraine as an indicator was the most easily applied and most reliable criterion for determining the marine limit in northern Melville Peninsula. A mean value for the limit of submergence determined by this method is 466 feet. This value is a little more than

rbed gro e above the limit of marine submergence. The depression running from left to right across t of ma ergence. View toward the east across the crystalline upland northwest of Hall Lake.

20 feet higher than the mean value indicated by the highest strand-lines. The values are plotted on Fig. 5.

Perched boulders

Perched boulders of large size resting on several smaller boulders are often so precariously balanced that they may be easily toppled over, Fig. 6. They may originally have been deposited by random dumping of englacial debris during deglaciation. Since it is not probable that such boulders could survive wave action and ice push at the shores of a post-glacial sea their presence indicates an altitude above the marine limit.

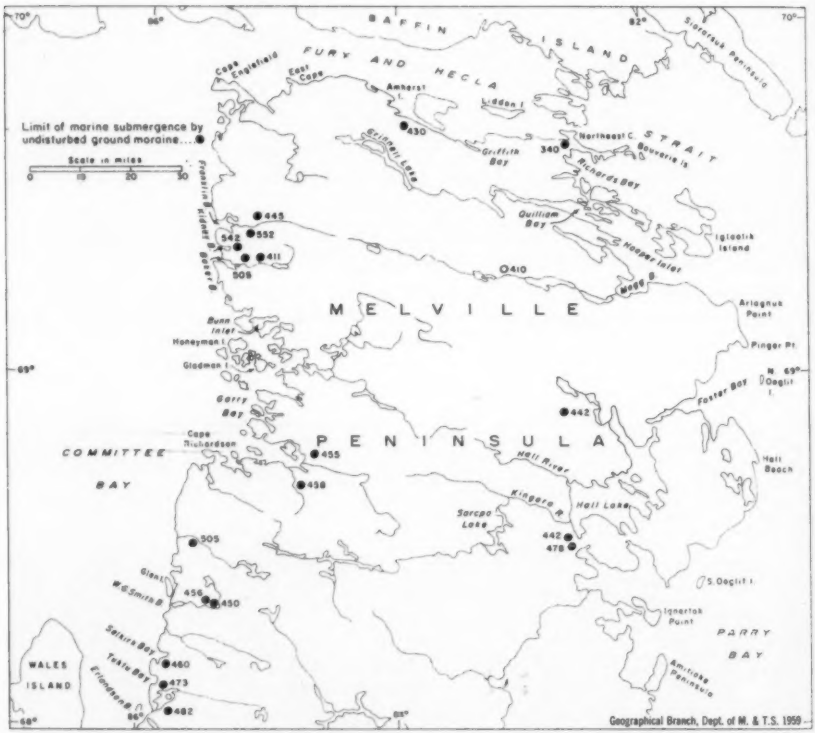

Fig. 5. Map showing locations and altitudes of undisturbed ground moraines.

Perched boulders must be interpreted with caution, however, since they may occasionally be seen at altitudes between sea-level and the marine limit. Thompson (1954, p. 173) suggests that rocks may be perched as the result of rockfalls or by rolling down snow banks to lodge on the boulders at the base of the slope. The writer has seen such perched blocks, however, and it seems that they can almost invariably be recognized for what they are. Others are less easy to explain. Several large perched boulders no

more than 30 feet above sea-level were observed on a low saddle between two Precambrian knobs near the south entrance to Bunn Inlet in Garry Bay. Many other boulders of a similar size but not perched were scattered about on the surface nearby. It is suggested that they may have been rafted into the area on ice floes and dropped into position when the ice grounded and later melted on the saddle. If they were deposited slightly above sea-level they might possibly have survived until they were lifted out of danger by continued emergence of the land. Local conditions usually make it possible to distinguish between perched blocks that are true indicators of marine submergence and those that are of more recent origin.

Perched boulders, where they occur on open hillsides away from steep cliffs and in association with others at the same altitude may be safely interpreted as having been deposited above the marine limit. The altitudes of perched boulders are plotted on Fig. 7 and from these data a mean value of 454 feet is obtained for the limit of marine submergence.

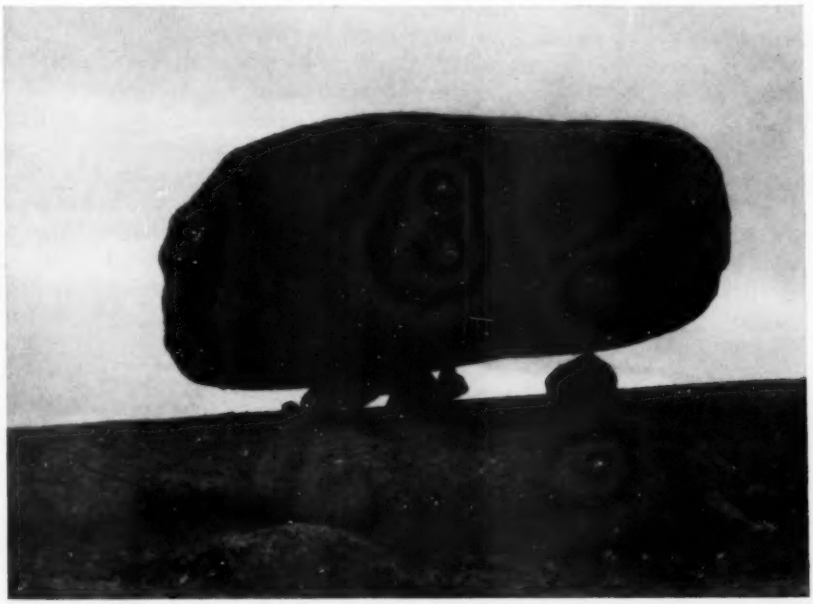

Fig. 6. Perched boulder above the limit of marine submergence.

Foraminifera

An attempt was made during the field seasons of 1957 and 1958 to determine the limit of submergence using foraminifera. Although the presence of marine microfossils in a sample of surface material may be taken

as conclusive proof of submergence, this criterion suffers from the same disadvantage as does the use of larger shells, since foraminifera are also largely benthonic and their presence only indicates a minimum figure.

Samples of surface material that seemed likely to contain foraminifera were collected in the field. These were subsequently examined by the Section of Stratigraphic Palaeontology of the Geological Survey of Canada.

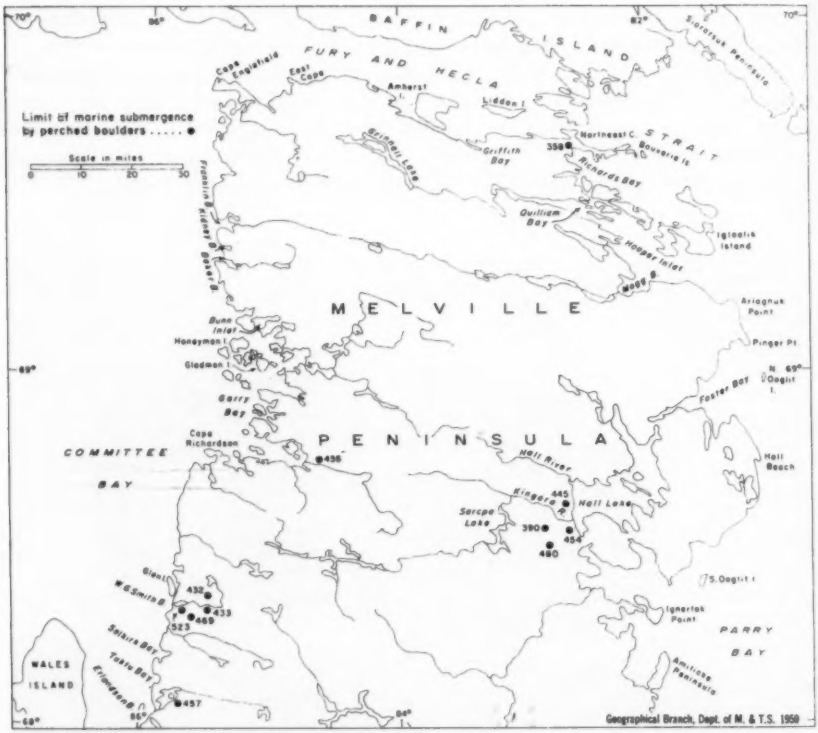

Fig. 7. Map showing locations and altitudes of perched boulders.

The most common species of microfossils discovered in the samples are listed in Table 1. The assemblage is very similar to that identified by Loeblich and Tappan (1953) from a collection made at Point Barrow, Alaska in the present offshore zone. An examination of the range table in their publication (1953, pp. 11-13) shows that with one or two exceptions all the common species from Melville Peninsula were taken at Point Barrow in depths exceeding 70 feet. Thus, even if these species were sampled in Melville Peninsula at the shoreward limit of their range, the actual marine limit, determined in this way, would still stand approximately 70 feet above

the level at which the fossils were found. In addition, Loeblich and Tappen found several species, notably *Dentalina ittai* and *Lagena opiopleura,* only in the comparatively narrow depth range from 70 to 160 feet below the

Table 1. Common species of foraminifera found in surficial deposits below the limit of marine submergence on Melville Peninsula, 1957–8.

Species	*Depth Range for Point Barrow (after Loeblich and Tappan 1953)*	
Elphidium orbiculare Brady	0 - 725 ft.	0 - 223 m.
Elphidium subarcticum Cushman	>70 ft.	>21 m.
Elphidium frigidum Cushman	>70 ft.	>21 m.
Buccella frigida Cushman	70 - 442 ft.	21 - 136 m.
Buccella musitata Anderson	0 - 725 ft.	0 - 223 m.
Oolina caudigera Meisner	>70 ft.	>21 m.
Lagena gracillima Seguenza	>70 ft.	>21 m.
Lagena semilineata Wright	>70 ft.	>21 m.
Lagena opiopleura Loeblich and Tappan	70 - 162 ft.	21 - 50 m.
Dentalina ittai Loeblich and Tappan	70 - 162 ft.	21 - 50 m.

surface. Whereas small numbers of many foraminifera may occasionally be found near the shore, these two species that are common in raised deposits in Melville Peninsula are never found in the present day beach zone at Point Barrow. If the habitat requirements for these species have not changed in the past several thousand years, the highest shells of these species probably lie at an altitude at least 70 feet below the marine limit. Lack of familiarity with the method prevented the writer from making any final estimates of the limit of marine submergence using microfossils. It would seem to be a valuable method to be employed where very accurate minimum figures are to be determined for a small area. It is also an ideal method for determining whether clay and silt deposits are of lacustrine or marine origin.

Summary of results

Table 2 presents the limits of marine submergence as indicated by the four principal criteria. These four methods do not of course yield strictly comparable results. It was usual to find that marine shells gave the lowest figure. Strand-lines, undisturbed ground moraine, and perched boulders, in that order, gave increasingly higher results. The highest shell localities in any area ranged in altitude from 258 to 525 feet. High strand-lines varied from 360 to 473 feet. The lower altitude of both may be discounted. It merely indicates that either no strand-lines have survived above that altitude or that the coastal topography was not suitable for their formation. In the above ranges the four altitudes determined by Blackadar (1958, p. 156) in the vicinity of Fury and Hecla Strait have also been excluded. These altitudes are samples determined during the course of field traverses and do not necessarily indicate maximum occurrences. The mean altitude of the marine limit determined by shells is 404 feet and by raised beaches 440 feet.

Undisturbed ground moraine and perched boulders were the most easily applied limiting criteria. The former ranged in value from 410 to 552 feet and the latter from 390 to 523 feet. The anomalous values that were obtained for both near Northeast Cape and are discussed below have been disregarded. The values give a maximum range of only 162 feet. The mean value for the limit of submergence as determined by undisturbed ground moraine is 466 feet. The value determined by perched boulders is 454 feet.

Anomalous results are indicated by the few altitudes obtained by the author in the northeast corner of the peninsula near Northeast Cape. Excluding the random altitudes determined by Blackadar as not being maximum values, Table 2 shows that the altitudes determined by marine shells, undisturbed ground moraine, and perched boulders were 278, 340 and 358 feet respectively. These altitudes are more than 100 feet lower than the corresponding means for the rest of the peninsula. It is possible that this area was covered by a residual ice mass located in northern Foxe Basin until very late. There is some indication of "dead ice" landscape southwest of Quilliam Bay to support this suggestion. By the time this remnant ice finally melted and the sea inundated the area to form strand-lines an isostatic recovery of 100 feet or more could already have taken place. This early recovery was not recorded on the land surface. Until many more data are available for the marine limit on Jens Munk Island and Baffin Island to the north this can be no more than conjecture.

In general the altitudes obtained in northern Melville Peninsula for the marine limit are considerably lower than those determined by Bird for Southampton Island. The limit, using the ground moraine method, in that area is about 600 feet (Bird, 1953, p. 24) whereas the limit by the same method on Melville Peninsula is only 466 feet. On an unpublished manuscript map on which isobases have been plotted using available data from Arctic Canada the contour pattern over Foxe Basin and Melville Peninsula suggests that this area was depressed by, and is now recovering from, the weight of an ice mass centred over Foxe Basin. The lower limits for maximum marine submergence in this area may be due to the presence of this ice until considerably later than the cover over Southampton Island. Because of the limitation of time and surveying technique it was impossible to determine whether the emerged strand-lines have been tilted.

An attempt has been made to show in Fig. 8 the coastal configuration of Melville Peninsula at the time of maximum extent of the postglacial sea. The western coastline did not differ greatly from its present shape. Since it was submerged to a depth of approximately 450 feet, arms of the sea extended in long estuaries 8 to 10 miles up the valleys of the major streams. The low headlands at the mouths of Franklin and Baker Bays were submerged as were the islands in Garry Bay, Wales Island and the adjacent coastal strip of Erlandson Bay. In Fury and Hecla Strait the Proterozoic lowland was submerged together with Amherst and Liddon Islands, Northeast Cape, and the Bouverie Islands. A small island persisted west of

Table 2. Highest observed altitudes[1] of post-glacial marine submergence in Melville Peninsula.

Locality		*Marine shells*	*Strand-lines*	*Ground moraines*	*Perched boulders*
Franklin Bay, 69°25′N. 85°10′ W.	1)	.	.	445	.
	2)	.	.	552	.
Kidney Bay, 69°22′N. 85°15′W.		477	.	542	.
Baker Bay, 69°18′N. 85°15′W.	1)	.	.	411	.
	2)	.	.	505	.
Gladman Island (Garry Bay)		378	.	.	.
Garry Bay, 68°56′N. 84°54′W.		437	.	.	.
68°45′N. 84°40′W.		258	.	455	455
68°43′N. 84°47′W.		.	.	458	.
Near unnamed river, 68°32′N. 85°35′W.		.	.	505	.
W. G. Smith Bay, near 68°22′N. 85°36′W.	1)	.	.	.	523
	2)	.	.	.	432
	3)	.	.	456	.
	4)	.	.	450	.
	5)	.	.	.	433
	6)	.	.	.	469
Selkirk Bay, 68°11′N. 85°50′W.		.	.	460	.
Tuktu Bay, 68°08′N. 85°50′W.		.	473	473	.
Erlandson Bay	1)	.	.	.	457
	2)	.	.	482	.
	3)	.	472	.	.
Four miles southeast of East Cape		340[2]	.	.	.
Amherst Island		.	250[2]	.	.
South shore of Fury and Hecla Strait, 69°44′N. 83°58′W.		.	360	430	.
South of Quilliam Bay, 69°28′N. 83°00′W.		.	403[2]	.	.
Near unnamed river, 69°18′N. 85°10′W.		.	.	410	.
Northwest of Hall Lake, 68°55′N. 82°40′W.	1)	428	468	.	.
	2)	442	.	442	.
	3)	368	.	.	.
Near mouth of Kingora River		.	470	.	454
West shore of Hall Lake, 68°38′N. 82°42′W.		.	.	.	445
South of Kingora River	1)	.	.	.	390
	2)	.	.	442	.
	3)	.	.	478	.
	4)	.	.	.	480
Parry Bay, 68°30′N. 82°40′W.		525[4]	.	.	.
68°22′N. 82°50′W.		328	.	.	.
Anomalous area					
Five miles southwest of Northeast Cape		278	.	340	358
Bouverie Islands		210[2]	.	.	.
Quilliam Bay		100[2]	.	.	.
Range of values[5] (excl. values for anomalous area near Northeast Cape)		258–525	360–473	410–552	390–523
Mean value (excl. values for anomalous area)		404	440	466	454

[1]All altitudes are in feet above sea-level. They were obtained with a Paulin surveying altimeter and have been corrected for pressure changes. All observations by the author unless attributed otherwise.

[2]Observations by Blackadar and not necessarily maximum altitudes for the areas.

[3]Doubtful strandline.

[4]After Mathiassen 1933.

[5]Observations by Blackadar have been omitted, because they are not necessarily maximum limits of submergence in the areas.

Richards Bay where altitudes exceed 900 feet. During emergence this island increased in area until, with the rising of the low divide separating Quilliam and Griffith bays it was joined to the mainland.

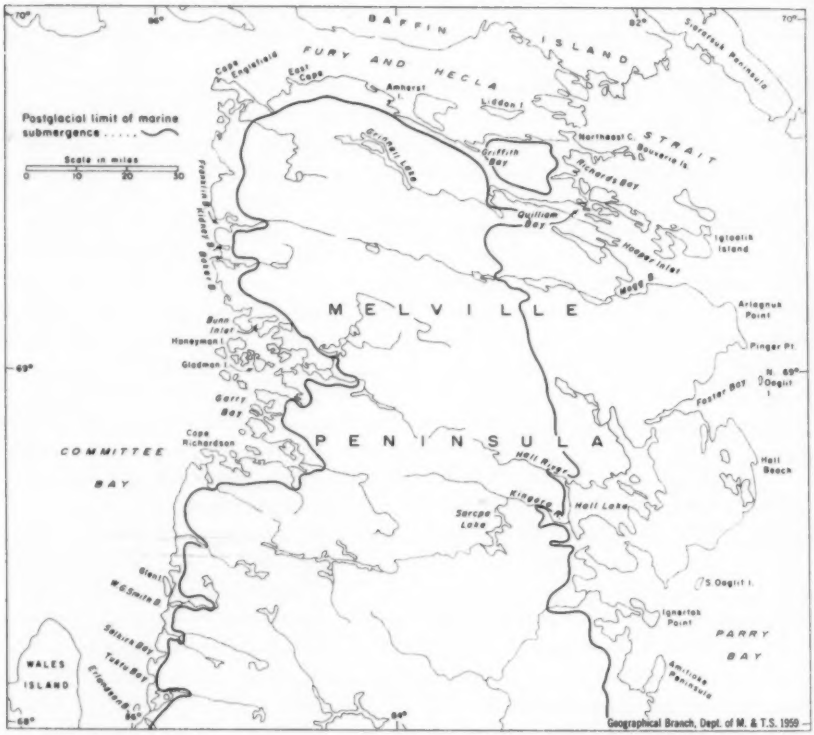

Fig. 8. Map showing the post-glacial limit of marine submergence.

With apparently only one exception the entire lowland on the east side of the peninsula from Amitioke Peninsula to Quilliam Bay was submerged. The sea covered the lower areas of Precambrian rock and penetrated into the valleys of many of the rivers draining east to Hall Lake and Foxe Basin. The steeply rising scarp that now forms the west coast of Hall Lake marked the shoreline at the marine maximum. This coast must have been similar in appearance to the present eastern shoreline of Foxe Basin between Wordie and Taverner Bays. In that area the Precambrian crystalline rocks rise gently from the shore in low knobs seldom exceeding 60 feet in altitude. Between Hall Lake and Quilliam Bay the coast appears to have been low and shelving. The only sedimentary area

that may have escaped submergence is a small tract south of Quilliam Bay. Here, at an altitude exceeding 400 feet on a plateau bounded on the north and south by limestone scarps, east-west glacial fluting is visible on the air photographs of the area. Well-developed strand-lines are present as far as the base of the north facing scarp. Blackadar (1958, pp. 163-4) points out that it is improbable that such flutings would be so well preserved had the area been submerged and subjected to wave action. He suggests that areas such as this may have been covered by ice that protected it until the land had risen above seal-level. This agrees with the opinion expressed on page 190.

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NOTES

OCEANOGRAPHIC OBSERVATIONS IN THE CANADIAN ARCTIC AND THE ADJACENT ARCTIC OCEAN*

The history of oceanographic exploration in the Canadian Arctic does not coincide chronologically with that of geographic exploration. In the early stages of arctic sailing the urgency of the discovery of the Northwest Passage took full priority over any other interest and later, during the period of the Franklin Search, little time could be spent in scientific observations. Several of the early arctic captains recorded observations on the natural history of the country and on more than one occasion instruments and methods were developed to sample the bottom and measure the more obvious currents. All the early expeditions made frequent references to local ice and weather conditions and in areas where shoaling water was suspected the soundings were listed in the journals.

One of the first arctic expeditions for which there are records of oceanographic observations is that of Sir John Ross in 1818. On this cruise sub-surface temperatures were taken with a Six's thermometer at 80 and 250 fathoms in the eastern end of Lancaster Sound. For his oceanographic observations Ross designed a type of water bottle that closed at a predetermined depth and a device for bringing up a sample of the bottom sediments.

In 1819 Parry took sub-surface temperatures and recorded depths and ice conditions in Lancaster Sound and Barrow Strait and in 1845 the Franklin Expedition was equipped with a number of bottles and copper cylinders in which messages were to be sealed. These containers were to be dropped into the sea at specific locations north of 65° N.

The second Norwegian Arctic Expedition in the *Fram* was in the Canadian Arctic from 1898 to 1902. During this time plankton collections, surface temperatures and bottom samples were taken at various positions in the region of Jones Sound; however, no sub-surface temperatures were recorded since the ship was not equipped for this type of work.

The voyages of the C. G. S. *Arctic* from 1906 to 1911 under Captain Bernier contributed much significant information concerning the surface temperature, salinity, and bottom topography in Parry Channel as far west as Winter Harbour and in 1916 the Canadian Arctic Expedition made a number of tidal observations at Cape Kellett and at three locations on the north coast of Alaska. During the late twenties various spot oceanographic observations were made by observers carrying out investigations in marine biology for the Fisheries Research Board.

The Danish *Godthaab* Expedition and the work of the United States Coast Guard Cutter *Marion* inaugurated the recent phase of oceanographic research in the North American Arctic in 1928 [1,2]. These ships carried out extensive oceanographic observations in Baffin Bay, Davis Strait and the approaches to the channels leading into the Canadian Arctic Archipelago. The work was continued by the Hudson Bay Fisheries Expedition sponsored by the Department of Fisheries in 1930, and the United States Coast Guard Cutter *General Greene* carried out further investigations in Baffin Bay and Davis Strait between 1931 and 1935. Additional surface observations of temperature and density

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were taken by the Royal Canadian Mounted Police Schooner *St. Roch* during the period 1935 to 1937 in the channels forming the southern route of the Northwest Passage [3].

After the war arctic oceanographic investigations became more specific in character. The growing national interest in the North and the demand for information on the circulation, ice cover, ice movement, navigability, and the productivity of the waters led to the organization of a number of oceanographic cruises the result of which has been a vast accumulation of oceanographic observations within a very short time.

The Fisheries Research Board of Canada has been instrumental in conducting a large proportion of this work beginning with the cruise of H.M.C.S. *Magnificent* and *Haida* to Hudson Bay in 1949. The same year the fisheries research vessel *Calanus* began investigations in Ungava Bay, and in 1951 and 1952 the motor vessel *Cancolim* of the Defence Research Board carried out oceanographic observations in the western Arctic. The surveys conducted from the icebreaker *Labrador* since 1954 have covered a large area of the eastern Arctic and have resulted in the first sequence of oceanographic observations to extend from Baffin Bay in the east to the Pacific Ocean in the west [4].

Ships of the United States have also been active in collecting arctic oceanographic information. During the last 10 years seven American icebreakers have carried out oceanographic surveys in the channels of the Canadian Arctic Archipelago. Many of these surveys have been conducted in close co-operation with the Canadian investigations and all data

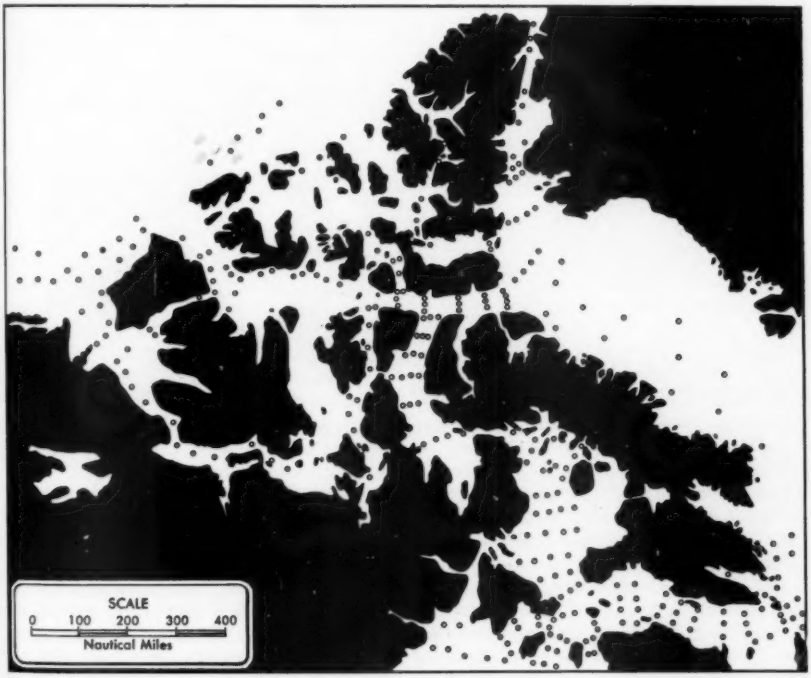

Fig. 1. Location of oceanographic stations.

have been freely exchanged between the two countries.

The most recent oceanographic programmes in the Canadian Arctic have been more confined in geographical coverage than the earlier reconnaissance surveys. Intensive investigations have been completed in Hudson Strait and Lancaster Sound by the Fisheries Research Board and the Hydrographic Service and in 1958 observations were taken from the I.G.Y. drift station T-3, which at that time was close to the western margin of the Canadian Arctic Archipelago.

Fig. 1 shows the distribution of oceanographic stations that have been taken in the North American Arctic within the last 30 years. The majority of the observations in the eastern region were taken from the Canadian icebreaker *Labrador* and the Fisheries research vessel *Calanus*. The stations in Kane Basin and Smith Sound were taken by the United States ships *Eastwind* and *Edisto*. In the western Arctic the United States ships *Burton Island* and *Requisite* and the Canadian motor vessel *Cancolim* have recorded most of the oceanographic observations.

A detailed bathymetric map of the region is unreliable since in many areas there is little or no information on the depth of water. Fig. 2, which is compiled from available sources, shows the general configuration of the bottom in the Canadian Arctic. Unfortunately, in the Queen Elizabeth Islands and the western region of Parry Channel the contours are based on only occasional soundings.

The deepest water in the Canadian Arctic Archipelago occurs in the eastern

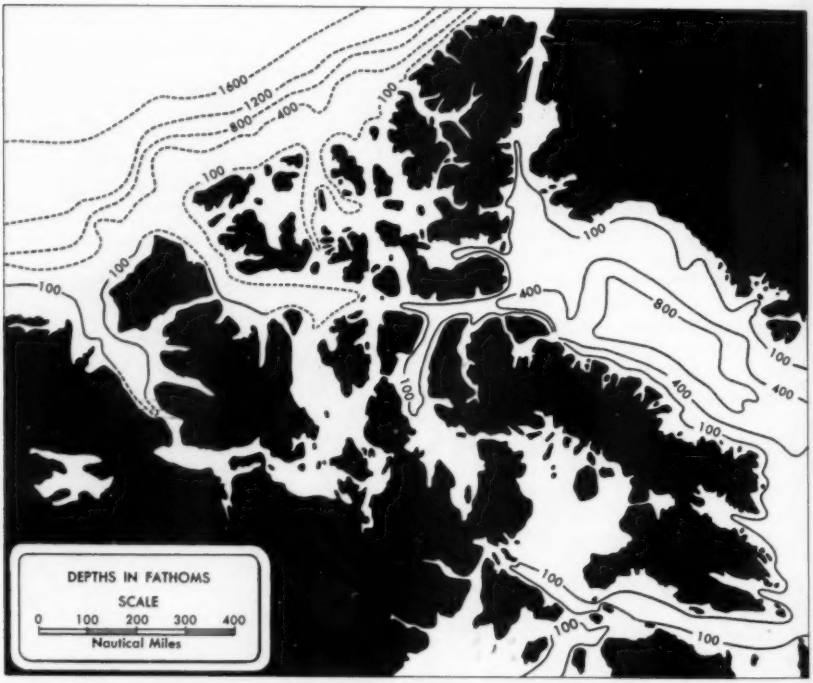

Fig. 2. Bathymetric map.

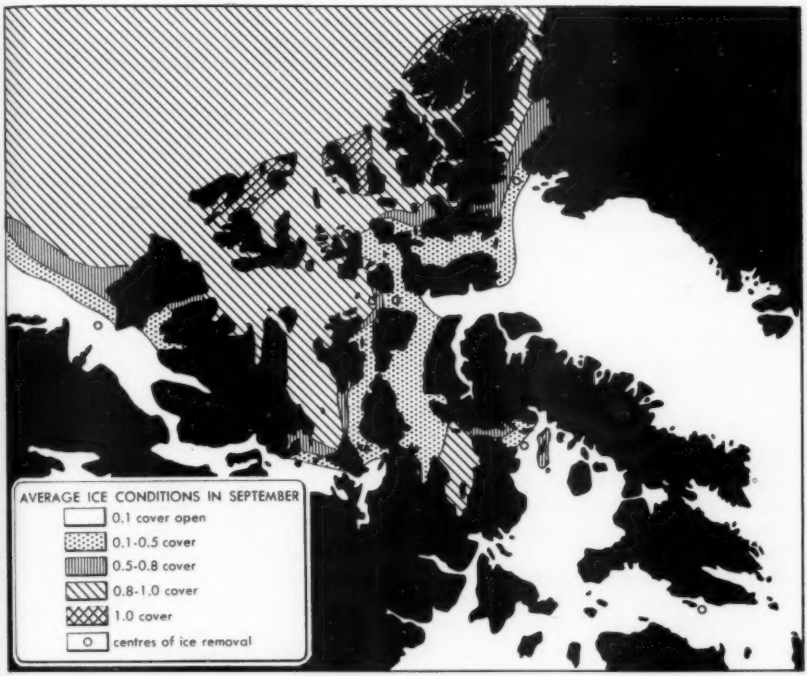

Fig. 3. September ice conditions.

end of Lancaster Sound where depths of 400 to 500 fathoms are common. In Lancaster Sound and Prince Regent Inlet the water depth varies between 100 and 300 fathoms, but to the westward the soundings decrease to about 200 fathoms in M'Clure Strait and Viscount Melville Sound. The sill depth through Barrow Strait is about 80 fathoms.

Few soundings have been taken in the channels in the northwestern part of the Archipelago or on the arctic continental shelf. The reconnaissance soundings indicate that the width of the shelf is approximately 50 miles off the coast of Banks Island and farther north increases to 100 miles. In the last year soundings of 150 to 200 fathoms have been recorded in the northern end of the Prince Gustaf Adolf Sea.

The distribution of sea-ice in the Canadian Arctic Archipelago is now fairly well documented and recently a sea-ice navigability atlas has been completed that will make available ice information in a form similar to that contained in ice atlases of the northern sea route [5].

Fig. 3 has been compiled from several sources including the Oceanographic Atlas of the Polar Seas, Part II [6] and the Ice Atlas of the Northern Hemisphere [7]. In several regions the distribution has been altered according to reports of observers who have been active in the Canadian Arctic, Grainger[8] and Learmonth (personal communication). The chart, which represents optimum ice conditions, shows that Lancaster Sound, Foxe Basin, and the passages south of Victoria Island are normally open, whereas in Prince Regent Inlet, Peel Sound, and Wellington Channel light ice concentrations are to be expected.

Recent analysis of ice records by Schule and Wittmann[9] has shown that

there are several areas where perennially unstable ice conditions can be expected. These areas form centres of ice removal and are indicated in Fig. 3 by circles.

Average conditions of temperature and salinity for the eastern and western Arctic are shown in Fig. 4. These curves have been constructed from observations taken in Lancaster Sound in 1957 and from the I.G.Y. drift station T-3, which in September 1958 was in the vicinity of the western end of M'Clure Strait.

Both curves show surface variations of temperatures and salinity caused by local sea ice. As would be expected surface temperatures and salinities are lower, 0°C and 29.90‰, in the Western Arctic since at the time the observations were taken the sea was totally covered with ice. In contrast, observations taken in the Beaufort Sea in September in areas of less than 5/10 ice cover show that under more comparable conditions very low salinities, and temperatures between zero and 6.0°C are characteristic of the surface waters to a depth of 30 metres [10].

The depth of the warm surface layer in Lancaster Sound indicates a prolonged period of surface heating and exchange with the warmer waters of the upper layers in Baffin Bay.

Similar temperature and salinity characteristics appear in both curves at about 180 metres but below this depth there is a uniform difference in both temperature and salinity that persists to the bottom. Bottom temperatures and salinity in the Western Arctic are almost constant at 0.4°C and 34.93‰; in the Eastern Arctic temperature and salinity at the bottom are typically 0.5°C and 34.50‰.

It is interesting to note that the slightly warmer interlayer at 75 metres that has been identified from the oceanographic observations taken from the Russian drifting station of 1950-51 is defined by temperatures of -0.7°C to -1.2°C. This feature does not appear in the 1958 T-3 records that show temperatures below -1.0°C from 10 to 180 metres; however, in 1952 Worthington[11] recognized a similar feature at positions in the same region as the Russian stations. At that time the negative thermal gradient between 50 and 150 metres was regarded as the last remnants of a seasonal thermocline. More recently Gudkovich[12] has interpreted this reversal of the thermal gradient as indicating the penetration of waters from the northern part of the Bering Sea into the arctic basin.

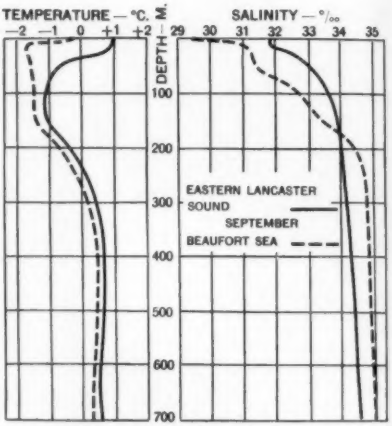

Fig. 4. Temperature and salinity curves.

The longitudinal profile through Parry Channel shown in Fig. 5 gives an idea of the east-west distribution of summer temperature and salinity in the Canadian Arctic Archipelago. In this diagram the bottom contour west of Barrow Strait is based upon very limited soundings and does not present an accurate picture of the bottom topography.

The typical sharp gradient of temperature and salinity in the surface layers is obvious and appears more pronounced in the west where heavy ice exists. Maximum surface temperatures of 2.5°C have been recorded in the eastern end of the section and the minimum surface temperatures of -1.6°C to -1.7°C normally appear in the region of Barrow Strait. The effect of the Barrow Strait sill is obvious in the discontinuity of the isopleths below a depth of 150 metres.

Temperature-salinity curves have been plotted in Fig. 6 for four representative stations in the Parry Channel system to show the variations in water characteristics from east to west. This graph shows the large variations in the surface layers and the pronounced differences in temperature and salinity that persist to a depth of 100 metres. Below 100 metres the curves assume a characteristic shape and can be considered representative for each specific region. temperatures of 0.4°C occur at about 500 metres and the salinity at depth is 34.93‰. These curves also show the similarity of the temperature-salinity characteristics of the deep water of Baffin Bay and the temperature and salinity features at depths of 250 metres in the arctic basin, an observation already discussed by Bailey[4].

Determinations of the concentration of dissolved oxygen in the water have been carried out on most of the recent

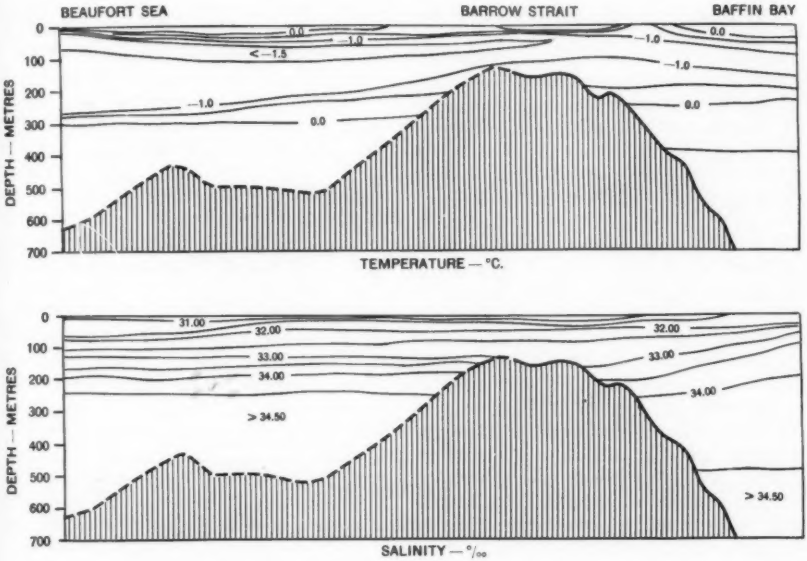

Fig. 5. Longitudinal profile of Parry Channel.

The variation of water characteristics above a depth of approximately 200 metres is apparent in the large spread of values in this depth interval and the east-west differences in the physical features below this depth are obvious in the displacement of the characteristic regional curves.

The graphs for the Eastern Arctic show an increase in temperature to a maximum of 0.8°C at 500 metres and a maximum salinity of 34.45‰ at the bottom. In the Western Arctic maximum oceanographic cruises in the North American Arctic. The observations that are confined to the summer months with few exceptions show that under similar conditions of ice cover there is little difference in the concentration of dissolved oxygen from east to west.

In eastern arctic waters where there are extensive ice-free areas and a constant exchange with adjoining basins the summer oxygen concentration varies from a maximum near the surface of 10.0 ml./l. to a minimum of 7.0 ml./l.

at 300 metres. In the Western Arctic under conditions of permanent ice cover a surface maximum of 10.0 ml./l. occurs after the period of peak surface run-off with a lag of about 1 or 2 weeks and the minimum of 6.0 ml./l. normally appears between 150 and 300 metres. Maximum surface values of dissolved oxygen of over 10 ml./l. usually occur during August and the minimum content, as little as 5.0 ml./l., is found in September.

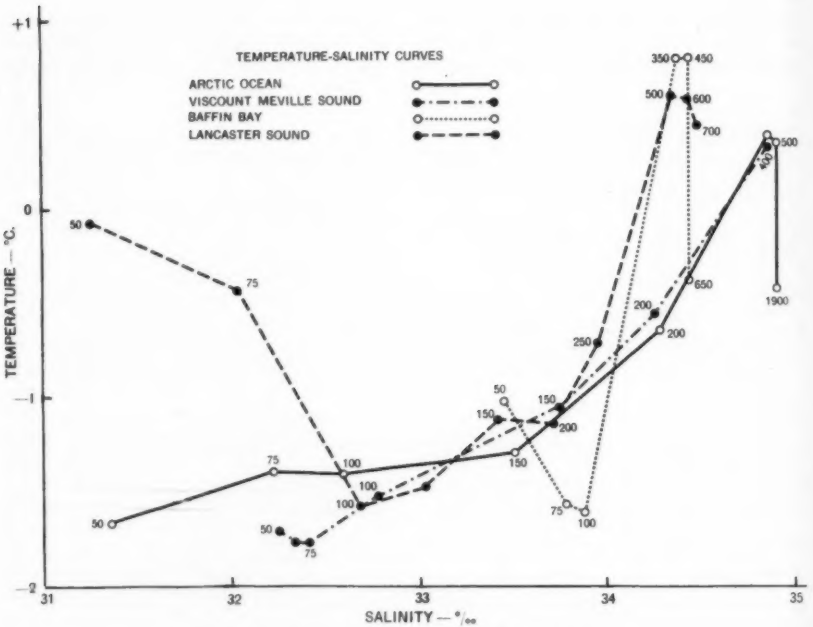

Fig. 6. Temperature and salinity in Parry Channel.

Calculations of the volume exchange through the channels of the Canadian Arctic Archipelago have been computed by several investigators including Kiilerich[1], Smith, Soule, and Mosby[2], and Bailey[10]. Recent surveys in Hudson Strait and Lancaster Sound by the Fisheries Research Board have determined the volume transport through these two major passages[13, 14].

A summary of recent information indicates that the total eastward transport of water from the Arctic Ocean through the Canadian Arctic Archipelago is of the order of 40,000 km.^{3} per year. Of this total approximately 16,000 km.^{3} per year pass eastward through Lancaster Sound and 13,000 km.^{3} per year enter Baffin Bay through Smith Sound. The remainder leaves the Arctic Ocean by way of Jones Sound and Hudson Strait.

Russian researchers have calculated the flow through the Canadian Arctic Archipelago based on the volume balance of the Arctic Ocean. Their results show a variation of values from 31,000 km.^{3} per year to the more recent figure of 8,000 km.^{3} per year [15, 16].

A. E. COLLIN

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FIELD STUDIES ON THE BEHAVIOUR OF SEA-DUCKLINGS

During the summer of 1959 the writer was engaged in studies on the behaviour of sea-ducklings in the Belcher Islands, Hudson Bay. This work is centred on an ethological study of eider ducklings *(Somateria mollissima)* with comparative observations on ducklings of old-squaw *(Clangula hyemalis)* and red-breasted merganser *(Mergus serratus);* it had been begun in the False River area, Ungava in the summer of 1958 [1, 2, 3]. Once again Mr. C. W. Nicol gave able assistance.

The objective of this work is to build up as complete an account as possible of the behaviour of the normal eider duckling in its natural environment, beginning shortly before hatching and ending with fledging. It is hoped that an account of the basic behaviour of this species will provide a sound foundation on which to plan analytical studies. The approach to this work is largely that of the present European vertebrate ethologists[4], but it is planned to develop the more "psychological" aspects of the work in future studies.

The most obvious single comment to be made about the behaviour of the eider duckling is that it is extremely complex, more so than has previously been recognized. This complexity is partly due to the mixture of innate and learned processes, which together enable the duckling to survive the difficulties of the pre-adult stages. One of the present aims therefore is to describe the part played by innate mechanisms and to correlate learning processes with them. A brief summary of the results to date follows.

Two or three days before hatching the duckling pushes its bill through the inner shell membrane into the air space

in the large end of the egg. At this time the duckling begins to make significant movements with its head and to vocalize. Movements of the developing embryo have previously been commented on[5], but it seems that the activities shortly before hatching have escaped the notice of ethologists. Ducklings in the pre-hatching stage were watched through an observation hole cut into the end of the egg, which was kept covered at other times.

The most obvious movement of the head at this time is the *upward nod.* This, as the name implies, involves the raising of the bill and it enables the egg-tooth to be brought into contact with the shell. As the bird is in a very cramped position curled up in the egg, this is the only means of rupturing the shell at its disposal. As the bird turns round in the egg a series of breaks is made around the large end and this is eventually pushed off by the bird's struggles. Bill opening also plays a part in the rupturing.

Most of the vocalizations of the bird before it hatches are what may be called "non-descript". However, some of them can be recognized as imperfect renderings of two of the innate signals that are used in appropriate situations after hatching. These are the *brooding note* and the *complaint.* The former is a monosyllable on a rapidly rising — or sometimes falling — note and the latter an insistent disyllable with the second note higher and rising. It seems that the former is used when the duckling is being brooded by the female and the latter when it is uncomfortable, and it is of interest that the only signals to be recognized from the egg to date are those that are used in basically similar situations after hatching.

After the bird has hatched the upward note takes on other essential functions. On emergence the duckling's first response is to the feeling of contact, particularly around its head, and it is believed that this is the mechanism whereby it achieves the position of optimum warmth and comfort under the female. Using the upward nod the duckling pushes its head up into animate crevices in its vicinity, such as the plumage of the female or between the fingers of the investigator, and if it is warm it will then rest. It is thought that this mechanism is likely to be of fundamental importance in the imprinting process, which has received so much attention in recent years, both from ethologists and psychologists. Detailed observations have therefore been made of this mechanism and it has been tentatively named the *brooding reflex*[6].

A third vocalization of significance is the *cohesion call.* This is a phrase of four or five ascending notes that is uttered at frequent intervals by the ducklings and almost certainly functions in the maintenance of contact between members of the brood. The adult female has a different call for the same purpose. The cohesion call is often used in conjunction with the upward nod and in this context the latter is used as a *greeting.* The full greeting involves both the head movement and the call, but at low intensity the movement may be used alone.

Yet another manifestation of the upward nod is the movement used in drinking. This is present from the time the bird first enters the water.

A call similar to the cohesion call is the phrase that we may call the *contentment notes,* for it is used when the duckling has achieved the satisfaction of food or warmth, for example. The phrase is basically similar to the cohesion call, but is faster, higher pitched, and more monotonic. When a brood of ducklings is feeding in the water the most common acoustic signals are these two here described.

When danger threatens a number of innate reactions may be brought into play. The most obvious of these is the *distress call.* This is similar to that in all other Anatidæ, but is not broken up into phrases as has been suggested[7], but is a continuously repeated monosyllabic and insistent piping. In normal circumstances it results in the alerting of the brood including the female, and an appropriate response of the brood will usually reduce the danger. If danger is very imminent the duckling will usually

crash dive if it is on water. This involves a backward and upward kick with the webs as the front of the body is forced down into the water. As our movie films show the time in which total submergence is accomplished is as little as one-fifth of a second.

At the time of hatching this crash dive is the only means available to the duckling for submergence. This is a very logical state of affairs as a crash dive may be essential for survival, but a smoother dive for feeding purposes is merely advantageous. The latter therefore is developed as a result of experience. When the duckling first learns that edible materials are to be obtained from below the surface it can only submerge by using a modified crash dive. By experience this changes into a smooth forward plunge so that the bird can submerge easily, but without the necessary haste and expenditure of energy of the crash dive. This *juvenile feeding dive* develops very rapidly during the first few hours of the duckling's experience of feeding conditions, and lasts until the duckling is about 3.5 weeks old. It is then replaced by the *adult feeding dive*. This involves a far less acrobatic submergence, being merely a kick forward and down from a head-under position. The young duck has become very heavy in its fore parts by this time and has only to put its head and neck under water to be over-balanced forwards and downwards. When the primary feathers develop fully from the age of about 8 weeks the young ducks begin to "fly" under water, using the wings partly flexed at the carpo-metacarpal joint as accessory propulsive organs.

The beginning of the feeding behaviour is particularly interesting as it involves both innate and learned behaviour elements. As soon as the duckling has left the nest and reached suitable conditions it shows an innate interest in *potential food objects*. These may be any objects that are small enough or dark or moving. The duckling investigates these and attempts to swallow them. From experience it learns that certain of these objects are edible and others are not. All this time its co-ordination is improving and on the second or third day it is able to catch insects in flight. The most attractive food objects however are Branchiopods or Amphipods, which are all under water. Hence the development of a feeding dive as explained above.

During these first few days preening has been developed on a basis of certain innate movements and the bird is able to dry out efficiently on emergence from the water.

Possibly the most interesting of all acoustic signals so far identified is the *question* or *investigatory note*. When the duckling finds itself in a situation that is puzzling to it — one that releases no definite reaction or that involves indefinite stimuli — it responds with this note. It is a thin ascending monosyllable lasting for about 1 second. This note may be released in both wild and imprinted ducklings by the sight of strangers on the horizon or of indefinite bird silhouettes in the sky. It would seem that the function of this note is to alert the other members of the brood to an unusual situation so that avoiding reaction may be taken if necessary. This is a most unusual item of equipment to find in a bird's armoury of behaviour patterns, but it seems to be a very definite and discrete mechanism.

The danger reactions of the eider ducklings also involve a response to the *alarm whirr* of the female. This is a descending throaty whirring call that results in the young "bunching" in the "danger shadow" of the female. The ducklings imprinted to the writer consistently reacted in this way in response to his alarm whirr and the presence of strange animals, including female eiders. The "bunch" is maintained as long as the danger call continues.

This very brief outline may give some idea of the results obtained in the study so far. No mention can here be made of many subsidiary items of interest nor of the evidence upon which these conclusions are based. A full report will be published on completion of the work, but it may be noted here that the study material has so far included 12 eider ducklings under the immediate care of

the writer in the field and imprinted to him in deliberately varied degrees. Control observations have been made on wild ducklings varying from one-day old to almost fledged and from single individuals to many hundreds at one time[8,9].

This work was made possible through a field grant from the Banting Fund received through the Arctic Institute of North America and greatly assisted by the generosity of Messrs. Fry-Cadbury Ltd., C.I.L. Ltd., Nestlé Ltd., Canada Packers Ltd., and Horlicks Ltd., all of which is gratefully acknowledged. Thanks are also due for assistance in the field to the Arctic Unit of the Fisheries Research Board, to the personnel of the M.V. *Calanus*, and to Mr. J. G. Walton, Area Administrator at Great Whale River.

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Glaciological studies of the Mendenhall Glacier, Alaska

In May 1960 a group of Japanese scientists from Hokkaido University, led by Dr. Akira Higashi, left Yokohama for Alaska to conduct a study of the Mendenhall Glacier for a period of 6 weeks.

The group included the following members: Dr. Higashi, Dr. Seiji Hashimota, and Mr. Kazuhiko Itagaki of the Physics Department; Mr. Hiromu Shimizu, of the Department of Meteorology; Mr. Sujio Kymano, of the Department of Geology; Mr. Katsuhiro Kikuchi and Mr. Tsutomu Takahashi, graduate students of the Department of Geophysics.

Objectives of the project were the collecting of large single ice crystals at a lake at the terminus of Mendenhall Glacier and glaciological investigations of the glacier to elucidate the mechanism of the formation of large single ice crystals. Single ice crystals of large size are urgently needed by physicists at Hokkaido University, who are studying the solid state physics of ice crystals. This is one of the reasons that prompted the University to send the field party to Alaska.

The planned glaciological investigations include measurements of the speed of flow at various points of the glacier; determination of crystal orientation, grain size, and impurity content in the crystal grain and grain boundary of each sample taken at different places. A geological survey of nunataks and cirques near the upper part of the glacier and studies of firn snow were also planned, as well as comparative studies of the Taku Glacier, which is apparently different from the Mendenhall Glacier in many respects.

The work schedule was planned as follows: first week, aircraft reconnaissance of the glacier and the Juneau Ice Field, determination of the location of observation sites from air photographs, establishment of a base camp at the terminus of the glacier; second week, search for and collecting of large single ice crystals at the glacier snout and putting them into cold storage in Juneau, establishing a base line across the glacier near the terminus for the determination of the speed of flow; third week, move to the second camp, routine glaciological work at two crevasses of medium altitudes; fourth week, move to the third camp, glaciological work at two

crevasses of high altitudes, special work on the firn of the ice field and on the geology of nunataks and cirques at the upper part of the glacier; fifth week, move to Taku Glacier, comparative studies of ice at the lower part of the glacier; sixth week, move to the upper part of Taku Glacier and continuation of the work of the previous week on the higher part of the glacier.

The project has been supported in part by the Arctic Institute of North America under contract with the Office of Naval Research and by Hokkaido University.

Investigation of the adjustment of the Eskimos at Barter Island, Alaska to rapid cultural changes.

The main objective of the field work carried out in March-April 1960 was the testing of a method that will make possible a relatively quick survey of the physical and mental health in an Eskimo community like that on Barter Island. After discussions with health survey specialists at the Harvard School of Public Health, the Cornell Medical Index Questionnaire (CMI) was chosen as the main instrument to be tried out in the field. The CMI contains 195 questions and was originally devised to collect a large body of medical and psychiatric data from American patients in a minimal amount of time. Revision of the questionnaire, necessary to meet the educational and cultural differences present in the village, was accomplished in consultation with various public and mental health specialists familiar with Eskimo concepts of health and disease.

Following a preliminary test at Barrow, the final form of the CMI was administered to the Barter Island Eskimos by three specially trained native interviewers. A 91 per cent sample of all adults over the age of seventeen ($n = 51$) was obtained. The results were then briefly compared with some of the medical records of the sample population at the native hospital at Barrow. While it is hoped that a much more thorough comparative analysis can be made during the summer of 1961, the preliminary findings suggest that the questionnaire can be used profitably in a non-western cultural setting. In the relatively few instances in which individual responses indicate a strong cultural bias, anthropological knowledge can be used to interpret the results correctly. For example, questions about difficulties in making decisions (as an index of "inadequacy") were answered positively by a large majority of Eskimo women. In view of the passive role played by women in this society, a resolute woman should be considered deviant rather than adequate. Further analysis of the questionnaire should contribute additional knowledge to the whole area of cross-cultural health testing.

The general anthropological investigation of the effects of rapid change on the Eskimos of Barter Island was also continued. The health survey and the main anthropological study are closely interrelated, the degree of physical and mental health serving as one important index of the overall process of adjustment.

NORMAN A. CHANCE

Dr. John C. Reed, Executive Director of the Arctic Institute.

INSTITUTE NEWS

Appointment of Dr. John C. Reed as Executive Director of the Arctic Institute

Dr. John C. Reed became Executive Director of the Arctic Institute on May 1, 1960 following 30 years of service on the staff of the United States Geological Survey, most recently as its Staff Coordinator. Trained as a mining geologist at Pennsylvania State College, he completed his Ph. D. in geology at Princeton University in 1930 and was also awarded the D.Sc. (Hon.) by the University of Alaska. His early research concerned mineral occurrences in the Pacific Northwest of the United States, but about 25 years ago he began working in the Glacier Bay region of Alaska and it is there that he established a scientific reputation in the tradition of A. H. Brooks and Philip S. Smith.

Dr. Reed was Chairman of the Arctic Committee of the United States National Committee for the International Geophysical Year and was responsible for the planning, carrying out, and subsequent transfer to other agencies of an elaborate scientific programme extending over several years.

Immediately before becoming Executive Director of the Arctic Institute he served as Chairman of the Board of Governors and so is fully informed about the plans for its expansion.

The Arctic Institute of North America is in some ways a rather complex organization. It is probably unique in being legally incorporated in two countries simultaneously and having its scientific responsibilities extend not only through the arctic areas of Canada and the United States but also into the Antarctic, and in some measure into Greenland. It maintains two offices, one in Montreal and the other in Washington, and has close and continuous relationships with the governments in Ottawa and Washington. Added to this it has a widespread and loyal body of members and Fellows and increasing contacts with polar scientists in many countries.

The director of such an organization needs to be a person of unusual capabilities, and the Institute has from its beginnings been most fortunate in attracting to the position men who combined well-recognized scientific achievements with experience in administration.

Gifts to the Library

The Institute Library acknowledges with thanks the gift of books, maps, and reprints from the following persons and organizations:

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GEOGRAPHICAL NAMES IN THE CANADIAN NORTH

The Canadian Board on Geographical Names has adopted the following names and name changes for official use in the Northwest Territories and Yukon Territory. For convenience of reference the names are listed according to the maps on which they appear. The latitudes and longitudes given are approximate only.

Greely Fiord 49 A S½ and 39 A S½
(Adopted March 3, 1960)

Adams Glacier	81°38′N.	74°11′W.	not Bishop Glacier
Charybdis Glacier	81°39′	75°20′	not Fiala Glacier
Scylla Glacier	81°37′	75°25′	not Cleaves Glacier
Air Force Glacier	81°41′	77°10′	not Tanguary Glacier
Nesmith River	81°49′	72°45′	not Weasel River
Mount Wiley	81°39′	73°57′	not Mount Wylie
Altered applications			
Lewis River	81°24′	73°35′	
Very River	81°36′	73°16′	

Challenger Mountains 340 N½ and 560 N½
(Adopted March 3, 1960)

Marvin Islands	83°01′N.	74°30′W.	
Bromley Peak	82°57′	79°08′	
British Empire Range	82°25′	78°30′	
M'Clintock Glacier	82°19′	76°34′	
Disraeli Glacier	82°26′	73°00′	
Ward Hunt Ice Shelf	83°09′	74°00′	
M'Clintock Ice Shelf	82°55′	76°42′	
Ayles Ice Shelf	82°50′	79°32′	
Milne Ice Shelf	82°43′	80°41′	
M'Clintock Inlet	82°45′	77°00′	not M'Clintock Bay
Disraeli Fiord	83°03′	74°32′	not Disraeli Bay
Milne Fiord	82°40′	82°00′	not Milne Bay
Ayles Fiord	82°49′	81°00′	not Ayles Bay
Phillips Inlet	82°08′	87°05′	not Phillips Bay
Cape Albert Edward	83°06′	72°34′	not Cape Albert
Alert Point	82°27′	86°25′	not Cape Alert
Bromley Island	82°56′	79°08′	not Bromley Point
Rambow Hill	83°03′	75°40′	not Rainbow Hill nor Rain Bow Hill
Bethel Peak	82°53′	79°32′	not Bethell Peak
Commonwealth Mountain	82°24′	76°30′	not Mount Moore
Disraeli Creek	83°00′	73°51′	not Ben Creek nor Benjamin Creek
Altered applications			
Cape Alexandra	83°05′	76°25′	
Mount Oxford	82°10′	73°10′	not Oxford Mountain

Chart 7705 Simpson Strait to Matheson Point
(Adopted March 3, 1960)

Established name			
Fram Point	68°37′N.	95°54′W.	
New name			
Lindström Island	68°33′	96°09′	

Chart 7706 Matheson Point to Spence Bay
(Adopted March 3, 1960)

St. Roch Basin	69°12′N.	95°09′W.	
Altered application			
James Ross Strait	69°24′	95°00′	

Prince of Wales Island 68 SW and 68 SE
(Adopted March 3, 1960)

Name change			
Sherard Head	73°21′N.	97°09′W.	not Sherrard Head

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